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THESIS

A PROPOSED MATERIAL REQUIREMENTS
PLANNING SYSTEM FOR NARF ALAMEDA

by

Baruch Eylon

March 1980

Thesis Advisors:

A. W. McMasters
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A Proposed Material Requirements
Planning System for NARF Alameda

by

Baruch Eylon
LCDR, Israeli Navy
B.S.I.E., Technion, Israel Institute of Technology, 1970

Submitted in partial fulfillment of the
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and

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ABSTRACT

The United States Navy is currently implementing a plan to consolidate the wholesale supply functions of the Naval Air Station at Alameda and the Naval Supply Center at Oakland. Improving supply support of the Naval Air Rework Facility Alameda in general and stock availability in particular is a vital part of the plan. Demand forecasting by workload driven material requirements planning (MRP) is being considered as a means to improve stock availability. This thesis begins with an overview of the MRP technique and the current supply support of NARF Alameda. It proceeds with the description and evaluation of a temporary MRP system that is currently implemented and uses it as a background for development of an MRP system that is designed to operate in a maintenance oriented environment in general and at NARF Alameda in particular. Finally, suggestions are made for transition from the temporary to the proposed system.

TABLE OF CONTENTS

I.	INTRODUCTION-----	11
II.	MATERIAL REQUIREMENTS PLANNING (MRP)-----	13
	A. BACKGROUND: PRODUCTION AND INVENTORY CONTROL-----	13
	B. MATERIAL REQUIREMENTS PLANNING CONCEPT-----	16
	C. ASSUMPTIONS AND PREREQUISITES-----	20
	D. MRP SYSTEM OUTPUT-----	25
	E. MRP AND CONVENTIONAL INVENTORY CONTROL-----	28
	F. IMPLEMENTING AN MRP SYSTEM-----	30
	G. CONCLUSIONS-----	36
III.	SUPPLY SUPPORT OF NARF ALAMEDA-----	38
	A. CONCEPT AND OPERATION-----	38
	1. Pre-Consolidation Support-----	40
	2. Post-Consolidation Support-----	42
	B. AUTOMATED DATA PROCESSING OVERVIEW-----	46
	1. Data Processing Equipment and Applications at NSC Oakland-----	46
	2. The Inventory Management Subsystem-----	49
	3. Data Files-----	50
	4. UADPS and MRP-----	52
	C. EVALUATION AND CONCLUSIONS-----	53
IV.	THE TEMPORARY MRP APPLICATION-----	55
	A. SYSTEM OVERVIEW-----	56
	B. MRP DATA-BASE-----	58
	C. SOFTWARE-----	66

D.	INPUT, OUTPUTS AND PROCESSING-----	70
E.	EVALUATION OF THE TEMPORARY MRP SYSTEM-----	73
V.	THE PROPOSED MRP SYSTEM-----	76
A.	PRM-MRP: PROBABILISTIC REPLACEMENT MODEL FOR MRP-----	78
1.	The Demand Distribution-----	78
2.	The Basic Model-----	80
3.	Extensions of the Basic Model-----	85
B.	SUPPORTING INFORMATION-----	89
1.	Outputs, Inputs and Data-Base-----	89
2.	Functions-----	90
3.	Algorithms-----	90
4.	Environment-----	91
5.	Information Network-----	91
C.	MATERIAL REQUIREMENTS ALGORITHM-----	91
D.	THE PRODUCTION CONTROL SUBSYSTEM-----	98
E.	DATA BASE DESIGN-----	111
1.	The BOM File-----	111
2.	FIC to IIC Translation Table-----	114
3.	Other Files-----	116
F.	SOFTWARE DESIGN-----	117
1.	File Maintenance-----	117
2.	Queries-----	131
3.	Requirements Generation-----	131
4.	General Purpose Subroutines-----	134
G.	SYSTEM CONFIGURATION-----	136
1.	On-Line Storage-----	136
2.	Off-Line Storage-----	138

3. Main Memory-----	138
4. Processing Time-----	138
5. Conclusions-----	141
H. COST-BENEFITS ANALYSIS-----	142
I. IMPLEMENTATION PLAN-----	145
VI. CONCLUSIONS AND RECOMMENDATIONS-----	148
APPENDIX A: List of Selected UADPS-SP Files-----	153
APPENDIX B: Supporting Data-----	154
APPENDIX C: Software Development-----	156
APPENDIX D: Updating Replacement Factors-----	162
APPENDIX E: Further Discussion of the PRM-MRP Model-----	166
LIST OF REFERENCES-----	171
INITIAL DISTRIBUTION LIST-----	173

LIST OF ABBREVIATIONS

ADP	Automated Data Processing
ASKARS	Automated Storage, Kitting and Retrieval System
ASO	Aviation Supply Office
BOM	Bill of Materials
CWF	Committed Workload File
DHF	Demand History File
DLA	Defense Logistic Agency
DMF	Demand Master File
DODMDS	Department of Defense Material Distribution Study
DPD	Data Processing Department
FIC	Family Identification Code
FMSO	Fleet Material Support Office
IIC	Item Identification Code
IM	Item Manager
MRP	Material Requirements Planning
MSIR	Master Stock Item Record (file)
NARDAC	Navy Regional Data Automation Center
NARF	Naval Air Rework Facility
NAS	Naval Air Station
NASA	Naval Air Station Alameda
NAVSUP	Naval Supply System Command
NIF	Navy Industrial Fund
NIIN	Navy Item Identification Number
NIMMS	Naval Air Industrial Material Management System

NISTARS Naval Integrated Storage and Retrieval System

NSC Naval Supply Center
NSCO Naval Supply Center Oakland
NSF Navy Stock Fund
OSI Operational Support Inventory
PCS Production Control Subsystem
PEB Pre-Expended Bin
POE Point of Entry
QFT Quarterly Family Tape
RDF Report Data File
RSF Requisition Status File
RSS Ready Supply Store
SER Shore Establishment Realignment
SLT Sorted Labor Transactions (file)
SPCC Ships Parts Control Center
SSD Specialized Supply Depot
UADPS-SP Uniform Automated Data Processing System-Stock Point
UICP Uniform Inventory Control Program
VOSL Variable Operating and Safety Level

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I. INTRODUCTION

The DOD Material Distribution Study (DODMDS) [7:8] attempted to determine the number and locations of wholesale activities necessary to provide efficient and cost effective distribution of materials. As a consequence of the recommendations of that study, the Naval Supply System Command (NAVSUP) initiated the Shore Establishment Realignment (SER) which will consolidate the wholesale supply functions of the Naval Air Stations (NAS) at Alameda, North Island and Norfolk with the Naval Supply Centers at Oakland, San Diego and Norfolk, respectively.

NAVSUP has specified that the consolidation is not to degrade the supply support provided currently by the NAS supply departments. However, it will be beneficial to the system-- and especially to the Naval Air Rework Facility (NARF) as one of the customers--to achieve not only reduced costs, but also improved service.

SER and the NARF's desire to maximize improvements has necessitated a basic reappraisal of the NARF/Supply System interfaces. The result [10] was identification of the following problem areas and possible improvements:

1. Response time, can be improved by:-
 - a. Mechanized requirements submission
 - b. Automated inventory control and materials handling
2. Stock availability, can be improved by:-
 - a. Demand forecasting by workload driven material requirements planning (MRP).

This study was done as part of the NARF's effort to clearly identify the problem areas in its supply support and find the best solutions to those problems. This study attacks specifically the stock availability problem and justifies why MRP is the solution.

The implementation of MRP is integrated into the consolidation process and the implementation of response time improvements in the system. As a result, the implementation of MRP consists of two phases:-

- I. Implementation of a temporary system that will run on existing equipment and will be used to gain experience with the system and build up the necessary data files. This phase will include the design of the target system.
- II. Implementation of the final system on the new computerized material handling equipment--namely, NISTARS/ASKARS (Naval Integrated Storage and Retrieval System/Automated Storage, Kitting and Retrieval System).

This thesis describes briefly the development and implementation of Phase I and uses it as a background for a proposed design and integration of the final MRP system with the standard ASKARS software and database.

II. MATERIAL REQUIREMENTS PLANNING

A. BACKGROUND: PRODUCTION AND INVENTORY CONTROL

Production and inventory control emerged as independent management tools. Production control, in the very beginning, was one of the functions performed by the line foreman. He ordered materials, hired people and decided what, how and how much to produce. As his workload increased, the first task to be assigned to someone else was the ordering of materials. Along with that, there were also a few attempts to develop a scientific approach to production control. However, general applications did not develop prior to World War II. After the war, industry needed maximum production since there was an almost insatiable demand for products. The main problem was how to make more and more products, not necessarily how to make them more efficiently [1:XIII].

This environment gave a big push to production planning and many techniques evolved, mainly oriented towards production with little consideration of the related inventory problems. Among those techniques were Gantt charts [1:13.33], Line of Balance [1:13.23], Network Methods [1:13.33] and Linear Programming [1:13.45]. It seemed apparent that these techniques had great potential to improve both production and inventory control which frequently deal with uncertainty, especially because of the little attention these functions had received from management.

Inventory control, on the other hand, developed in a more "natural" way. The concept of economic lot sizing and reorder points was first presented by Ford Harris in 1915 and later developed by R. H. Wilson in 1934 [14:3]. But it was only after World War II that that theory had seen real application, after stochastic inventory models were developed and could use this theory in a more realistic way.

The biggest problem in applying the scientific techniques in industry has been the fact that companies were not ready for them because they had not begun to solve many of their basic problems in controlling production. Lists of materials and parts were not in existence. Production depended on the memories of people in the company. Under such conditions, no scientific method which needed data could be implemented [1:XIV].

The second decade after World War II has seen a reversal of that situation. Supply caught up with demand and low-cost, high-quality products were available in large quantities. Meeting competition required tightly controlled factories and most efficient use of men, money and materials. The responsibility to achieve the necessary improvements has been given to the production and inventory control function [1:XIV].

Production and inventory control were separate functions with conflicting natures. Lack of data and experience was another problem. Together they created a problem too serious to ignore.

The introduction of computers provided the means for solving many of the problems. The use of computers:

1. Allows storing information.
2. Enables processing and efficient use of that information.
3. Makes the system more responsive because handling of data, updating and retrieving are facilitated.
4. Allows integration of both production and inventory control.

First attempts to use computers in production failed [17:3]. The main reasons were:

1. Companies had failed to develop discipline in information handling.
2. The system being implemented was a mechanized version of the manual system. Since the manual system was never taken seriously enough to work satisfactorily, there was no chance for the computerized system to succeed.

However, those attempts established a sound foundation on which better systems were developed, supporting initially only parts of the various functions of production and inventory control. Later, integrated systems supported, or more accurately, maintained the whole production system.

One of the techniques which emerged and benefitted from the use of computers was the Material Requirements Planning (MRP) method. This method, which is used as one module of the production and inventory control system, uses the production schedule as the basis for inventory control. By doing that, there are no longer two different systems, but one integrated system which:

1. Uses the same data for both production and inventory control.

2. Provides built-in mutual feedback and response in the system and no longer depends on activities of separate functions in the organization.

B. MATERIAL REQUIREMENTS PLANNING CONCEPT

Material Requirements Planning (MRP), or Requirements Planning System (RMS) as called by others [1:17.2], is a technique for determining the quantities of components that will be required to build a product or carry out a production schedule.

The term "components" is usually used to cover both sub-assemblies and parts from which a product is made. As far as the technique is concerned, there is no difference between them and the only requirement is to know that they are required to build the item and in given quantities for assembling one product.

The direct objective of the system is to generate requirements in fairly precise time periods so that the right information will be available to get the required components into the regular production process, rather than using lists of "hot items" to complete the assembly of an order.

A manufacturing environment, as opposed to maintenance, is the best for implementation of this technique because the output of the system is well defined in terms of the items being produced, the components from which they are composed, their quantities and their time schedule. Only a manufacturing environment can provide the inputs that MRP needs--with sufficient accuracy--to ensure effective operation.

The MRP concept is described in Figure 1. The basis is the master production schedule, which is a "given" to the MRP system. The production schedule states which products are to be produced and when. In addition to that, the system also uses two other files:

1. Inventory file - This file contains data about all items used/produced in the organization. The information about each item includes elements such as quantities (on hand, on order), sources of supply, price, lead times and associated costs.
2. Bill of Materials file - This file contains the product structure data for each product which may be produced by the company. In addition to quantities of subassemblies and parts, the file will also contain numbers of drawings or other documentation required in the production process.

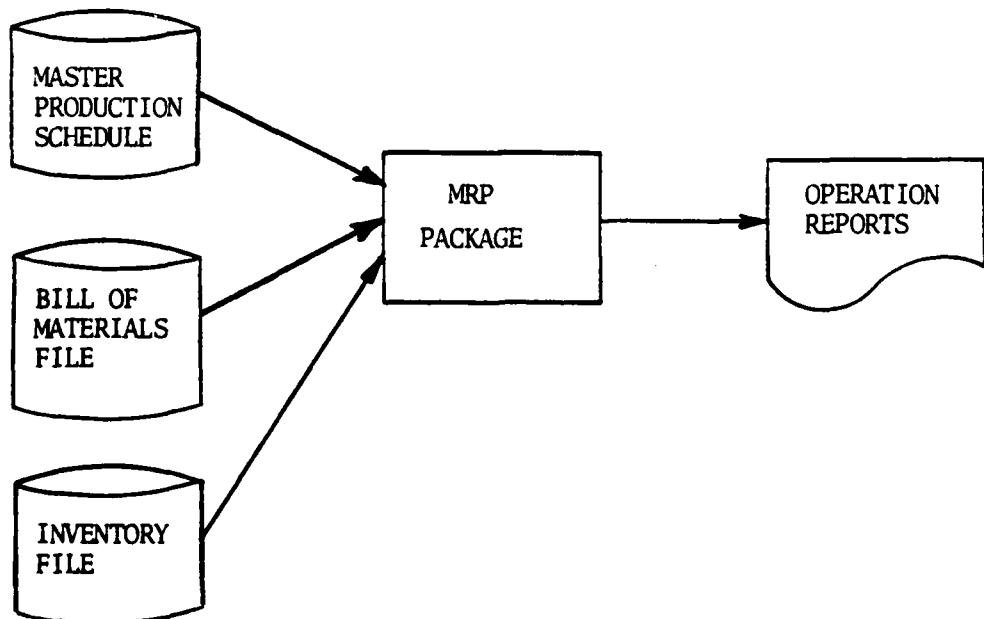


Figure 1: A Material Requirements Planning System

The most important data item in these two files is the item identification number (part number). This is the common field that connects all files and allows direct access to get the required information for the computations. It is essential to eliminate ambiguity in those numbers on the one hand and, on the other, to have meaningful numbers which may simplify operations of the system and prevent mistakes.

The process by which requirements are determined is as follows. First, the master production schedule is used to determine which products will be produced in the following period. For each order, relevant data from the bill of materials file is retrieved and added to the "file" of required materials. At this point, each product is "exploded" into its basic components and total quantities are computed for each item (part number).

It is important to note that the production schedule for more than one planning period can be used. But since the time the items will be needed is very important (it might be very costly to keep them when not needed), we would like to sum up requirements separately for each period and as close as possible to the day of use as lead-time allows. Adding the requirements for all periods and orders gives the "gross requirements," i.e., a list of all components required to carry out the production schedule.

When the gross requirements are available, they are compared with the information in the inventory file. For each item, the gross requirement is compared with the total of

quantities on hand and those on order which are due in the relevant period. If the gross requirement is greater, an order should be placed. A simple rule to determine the order quantity suggests itself--order the amount which is missing. Thus, it may be that the same item will be required for the next period also. This requires a more sophisticated rule which will be discussed separately.

The way the process was described is most fitting when there are no deviations from the production schedule. Obviously, this is not always the case. As it turns out, the same logic can also be used in a continuous operating environment (including deviations from schedule) by regeneration of the requirements as described above. In other words, the updated production schedule is used periodically to recompute the requirements. This process is called a Schedule Regeneration System [4:99].

Another way to compute requirements without repeating all computations for periods which were previously analyzed is called the "Net Change Material Requirements Planning" [4:102]. The basic idea here is to keep track of the original gross requirements for each period and then to compute gross requirements for changes in the production schedule as they occur by adding/subtracting them according to the specific change in the schedule. This results in a new gross requirement which has to be compared to available stocks (on hand and on order) to give the net requirements.

The computation is relatively simple when the change is an addition of a job, but it becomes very complicated to keep track and "to free" allocated materials when the change is a deletion of a planned job.

It may seem that the "net change" alternative is much better than the regeneration system. This is true if there are no changes in the schedule. But if this is not the case, continuous updating of the whole data base is required along with the necessity for incessantly reacting to the system's output. That usually creates a "nervous" reaction of the system, i.e., order changes and manual follow-up, which is more a disadvantage than an advantage. Of course, there is always the trade-off between the "nervous reaction" and the lack of reaction of the system. A short (one month) cycle time (planning horizon) may provide a good compromise, thus justifying the use of the simpler regenerative system.

Figures 2 and 3 describe the "regeneration" and net change alternatives. From the flow charts it can be seen that the "net change" algorithm is more complicated. But if there are only few changes in the production schedule, some work may be saved.

C. ASSUMPTIONS AND PREREQUISITES

Introduction of an MRP system as an inventory control tool in a manufacturing organization is not just a matter of management's decision. There are some assumptions and prerequisites about the environment in which MRP is to

The process is run periodically

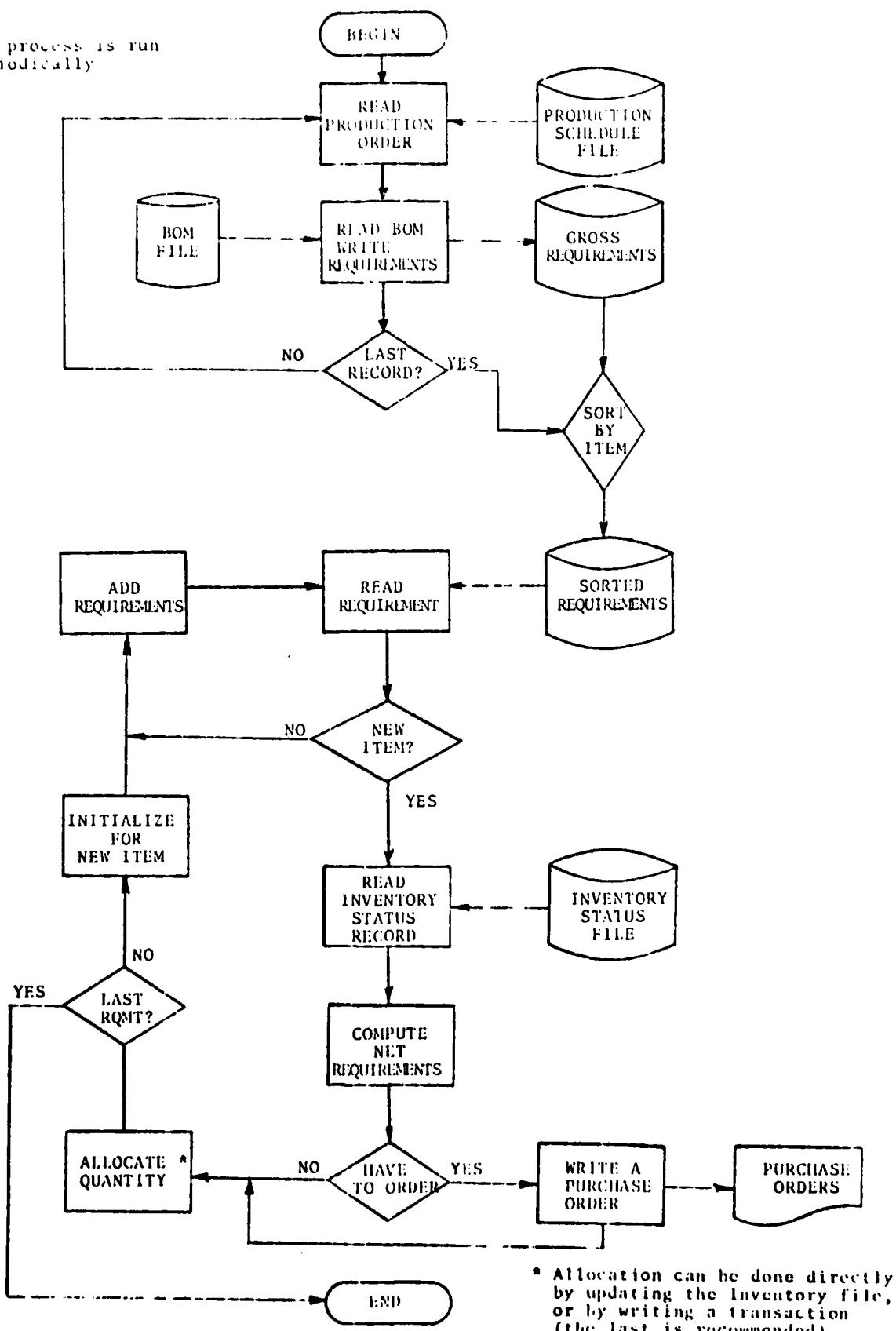


Figure 2: "Schedule Regeneration" MRP.

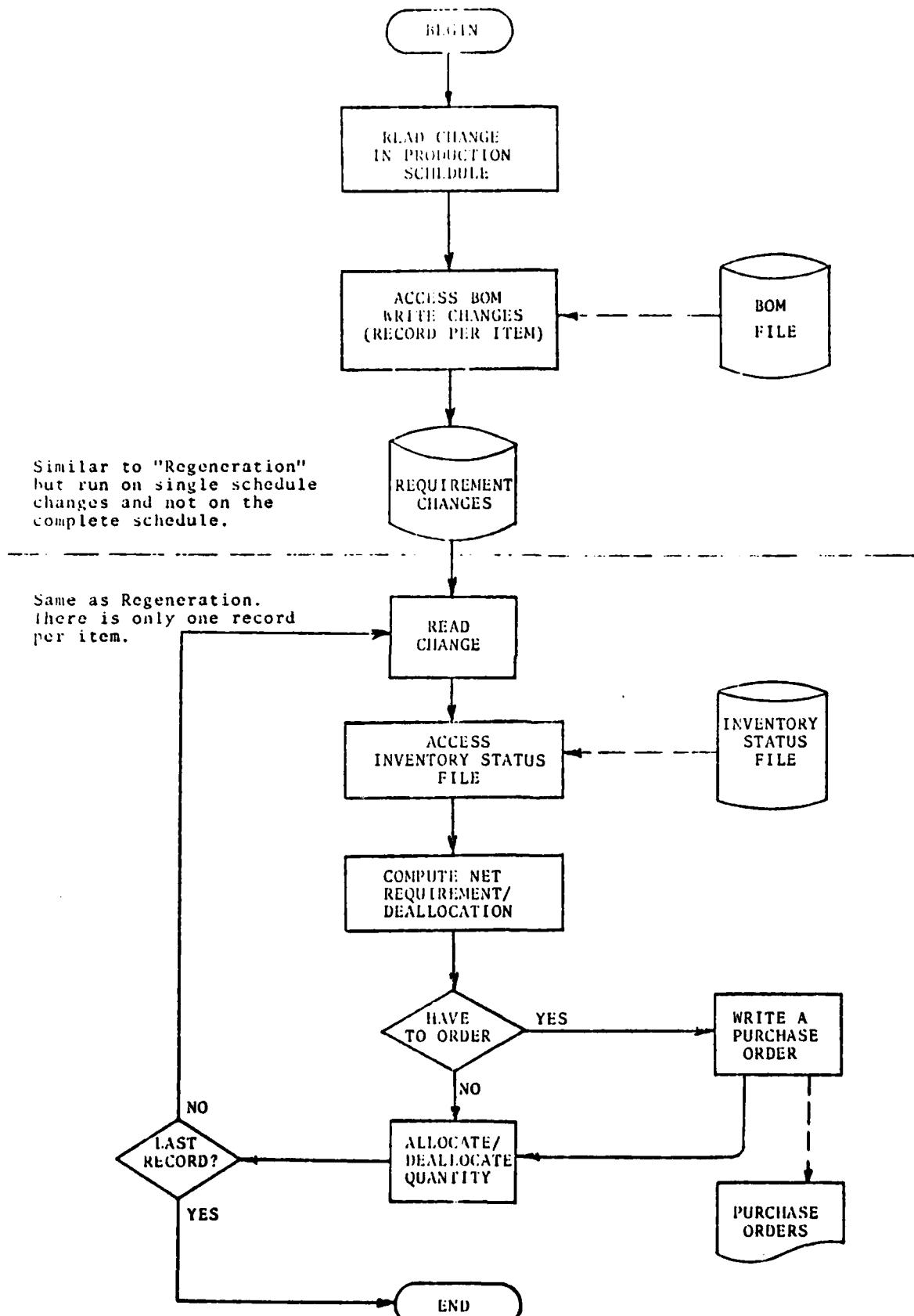


Figure 3: "Net Change" Material Requirements Planning.

be implemented. The preconditions for implementation of MRP are listed below:

1. Existence of Automated Data Processing (ADP)

The amount of work involved in manual computation of requirements is prohibitively high. A manual MRP is impractical except for very simple products. The assistance of computers is required for processing of massive numbers of lower-level items.

2. Existence of a Master Schedule, Bill of Materials File and Inventory Status File

These files are the basic input for the MRP systems and it is obvious that without them the system would not work. But the existence of such files is not enough because files can have these names and contain different data than needed. The Master Schedule should be stated in terms of entries in the Bill of Materials file (BOM), i.e., having a product to be produced allows access to the Bill of Materials file to get a list of components and quantities required to produce that item. A similar relationship should exist also between the BOM file and the inventory file to obtain the status of each component needed. The common key here is the Item Identification Code (IIC).

3. Unambiguous Item Identification

This is usually achieved through unique codes such as part numbers. Although this subject seems to be straightforward and simple, it is actually very difficult to maintain a simple unambiguous identification method when dealing with hundreds of thousands of items coming from many sources.

4. Data Integrity

Files must be kept updated and consistent with each other. Changes in design require changes in the BOM file and may result in changes in quantities to be ordered. Therefore, all files should be updated simultaneously since changes in one may cause changes in another.

5. Known Lead-times

At the very least, there should be estimates of lead-times to allow reordering on time.

6. Availability of Components

All components of a product must be available when the production order is released. Although this assumption may not hold in some cases, it may result in simplification of the MRP model. A more complicated version may take into account the production schedule for a specific item and allow arrival of certain items during the production process. This, of course, is more difficult to implement and the benefits are outweighed by the problems it causes [4].

7. Process Independence

It is assumed that there is no interference between different production orders. The production master schedule should incorporate all relevant considerations.

The existence of all these factors in an organization no more implies the applicability of the MRP model than their absence implies their inapplicability. Basically, an MRP is "applicable to manufacturing environments that are oriented towards fabrication of components" [4:42], and the problem of

satisfaction of preconditions may be solved if the decision is made to implement MRP.

D. MRP SYSTEM OUTPUT

What is the MRP system expected to produce? Basically, every production/inventory control system is expected to provide the Inventory Control Manager with information that will answer the following three problems:

1. What to buy?
2. When to buy?
3. How much to buy?

The question of what to buy gets a straightforward answer from the system by computations of gross and net requirements. This is a "simple" decision when the production schedule is known and the composition of each product is fixed. Those two factors are preconditions of the MRP system.

The problems of when to buy and how much to buy are more complicated and interdependent. The decision may be affected by many external factors such as sale prices, seasonality, expected shortages because of instability of the market or other similar factors. Of course, such factors cannot be accounted for in a system which runs according to a predetermined algorithm because they apply only to specific items, and the only simple way to improve results is to correct manually the "proposals" of the system.

However, there are other factors which determine the quantities and timing. The basic factor is, again, the

production schedule. When it is split into specific tasks, an exact determination can be made as to how much is required at any point of time. When inventory (on hand and on order) is compared against requirements, the result is information about definite quantities which are to be available at certain times. Consideration of lead times gives the time for ordering.

The decision whether to follow that basic ordering schedule has still to consider trade-offs between ordering costs and holding costs since the same item may be required for more than one period of time.

That problem is solved by the least unit cost method [4:511] which calculates the combined ordering and holding cost per unit for each period separately, for two periods combined, for three periods, and so on, and selects whichever method produces the lowest unit costs.

Even though we have discussed the output contents before, it should be recognized that the way it will be presented depends on the user (and the ADP responsiveness, of course!). If the organization is highly computerized, and its procurement activities interact with organizations which are also highly computerized, it is likely that the output will be magnetic tapes which will contain all purchasing orders. These tapes will be sent to the sellers, which in turn enter them directly into their automated system. (Such a method is used for procurements in the Israeli Navy.)

If the system is not that well developed, the purchasing order containing all data required to buy the item will be printed by the computer. Those orders will then have to be reviewed and processed.

The MRP system may also produce many other management reports. These will usually concern specific problems which exist in the plant. Typical reports of this kind are:

1. Exception Report

This report presents exceptional events (shortages or unused inventory) which should be reviewed by someone.

2. Inability to Meet Production Schedule

It may happen that the production schedule was determined without checking its feasibility. If so, the schedule is impossible to follow because of shortages/long lead times.

3. Inquiries

These can be helpful to the production scheduler to prevent events which will later appear as an inability to meet schedules. Direct access to the system files using the MRP algorithm may help the scheduler to decide if inclusion of a production order in a certain period is feasible or not.

The specific outputs should be tailored to the needs of the specific users and the capabilities of the system on which MRP will run.

E. MRP AND CONVENTIONAL INVENTORY CONTROL

There are many good reasons for holding inventories. In a manufacturing environment the most important reason is to prevent production shutdown and allow smooth operations. Various techniques were developed to control inventories in order to optimize (by minimizing total costs) operations of the whole system.

Among the most famous "conventional" inventory control methods are the following:

1. Perpetual (Continuous Review) System

Two inventory levels (RO = reorder objective, ROP = reorder point) are determined for each item. Inventory status is reviewed with each transaction and when inventory reached the ROP level a fixed quantity (RO - ROP) is ordered.

2. Two-Bin Inventory System

This is a simplified continuous review system. The ROP is the quantity held in one bin and the RO is the quantity in two bins. When one bin runs out of stock, the quantity to fill it is ordered.

3. Periodic Review

This system reviews inventory status at fixed intervals of time. Upon review, an order is placed for the quantity required to bring inventory to RO.

4. Optional Replenishment

This is also a periodic review system, except that an order will be placed only if inventory is less than a pre-determined quantity (ROP).

All those policies use the basic "EOQ model" with appropriate adjustments of its assumptions to real life. After selecting the model, the required data is found (or decided upon by a "rule-of-thumb") and used to determine the "order quantity," the "reorder point" and "reorder objective." Since the models are used to determine "what, how much, and when" to buy in the present and for future use, all of those techniques have to use forecasting methods to estimate future demand and that forecast (based on past demand) becomes the basis for all future operations.

On the other hand, MRP uses the production schedule which, of course, provides a sound basis for the computations and promises smaller deviations from the plan to actual performance.

That advantage also has a price. In order to be able to operate an MRP system, a production schedule is needed in advance and, for each product, the system has to have an accurate bill of materials. This is not the case with the other techniques. Since they do not depend on a specific production plan, they have no need whatsoever for the master schedule or bill of materials. All that is needed is past demand translated to a forecast which helps to determine all inventory levels.

Another major difference lies in the behavior of the systems in an environment of changing products. In such a case, conventional methods may cause a build-up of "dead-stocks" and shortages in the required new items, whereas MRP will "sense" that in advance and stop ordering the items not

needed and prepare the required materials. Because of those changes, traditional techniques also suggest higher safety stocks.

Generally speaking, MRP will be more responsive to production because of the fact that it uses the same plan and objective--the production schedule. This is not so with the traditional methods which do not consider it at all.

In summary, when comparing MRP to other conventional production and inventory control systems, one can identify the following advantages and disadvantages:-

<u>ADVANTAGES</u>	<u>DISADVANTAGES</u>
1. Based on production schedule	1. Requires a production schedule
2. Allows small or no safety stocks	2. Requires a large, high quality data base
3. Responsive to changes in demand	3. More complex, more difficult to use
4. Easily identifies "excess" items	4. More difficult to implement
5. Does not have to keep historical data	

This comparison shows that MRP has advantages as well as disadvantages. Before a decision is made to implement it, all factors have to be considered to determine that the investment (money and effort) is worthwhile.

F. IMPLEMENTING AN MRP SYSTEM

Before addressing the specific problem of implementing an MRP system, a few words should be said about implementation of an ADP (Automated Data Processing) system in general.

The process of implementation usually begins with the very first idea about system change and it terminates when the system has been successfully integrated with the operations of the organization. This process involves the study of the new desired application, determination of the objectives, participation of the future users in the design of the "new" system and selection of the steps and timetable to change the system from its present configuration to the desired one.

In this specific case, the steps which will be addressed are the initial study prior to the decision to proceed to actual implementation, the various considerations which should be discussed in that analysis, and the basic steps towards implementation.

The first problem that should be addressed is whether the system is mature enough for MRP. The problem is not one of satisfying prerequisites, but whether the change to MRP is too big for the organization. Nolan and Gibson [3] identify four stages in the growth of EDP systems in terms of the applications, EDP personnel, and formal management techniques applied to each. The four stages are:-

1. Introduction of simple applications (such as payroll and accounting).
2. Specialization to develop a variety of applications.
3. Moratorium on new applications and emphasis on control.
4. Specialization for data-base technology and tele-processing.

Each succeeding stage requires more skills, more sophisticated

techniques, and a more mature environment than its predecessors. In order to proceed to a higher stage, there should be experience with lower-stage applications which naturally form the basis for evolution. In the case of MRP it will be obvious that the organization should have previous experience in developing and using at least separate systems for production and inventory control. At this point, the problem will involve "only" their integration and not the much more complicated problem of creating and integrating an advanced system.

Given the environment, the existence of fundamental skills and the acceptance of the decision and its justification, the following actions are to be taken:

1. Analyze available and required input for MRP.
2. Design the new MRP system.
3. Identify required changes in existing data files and their relations to other applications.
4. Determine specific output from the MRP system.
5. Identify required changes to existing software and development of new programs.
6. Develop or buy software: "make or buy!"
7. Prepare a plan of how to switch from one system to the other.
8. Train personnel.
9. Prepare a timetable for carrying out those actions.
10. Carry out that plan.

The first problem that comes up after knowing what to do is deciding who will do it. It is possible to assign the job to either an outside consultant or to the organic EDP department.

Although bringing in an expert may sometimes cause troubles (especially dissatisfaction of in-house personnel), this might be a good solution. On the other hand, using the organization's people develops their skills, makes use of their familiarity with the system and prevents the problem of later being left to maintain a system which was developed by outsiders.

Another problem is that of designing the new system. It is desirable to have the users participate in that process and contribute their knowledge of existing problems and suggestions for system improvement. A steering committee, composed of users and EDP people, can serve as the body to gather essential information about the old and new systems.

Two other problems are interrelated. These are the problems of changing existing software and developing new programs. There are MRP software packages. However, the problem with these software packages is that they were not designed for the specific user that is going to use the system, and since the software package is not flexible, it will require changes; this, of course, should be avoided. The same rationale should also be used to avoid unnecessary expansions. The developers should concentrate on the minimum expansion and changes required to accomplish the objective but avoid making them too restrictive and inflexible with respect to later developments.

An important factor in the development of the new system is planning the process of switching from using the old system

to the new one. It is highly desirable not to implement all changes at one time. It would be better to first change the structure of the data files and to continue using old programs (although that also requires minor changes), then:

1. Use converted data files to develop and test new software.
2. Run old and new systems in parallel. Compare test files and outputs with current system.
3. After new software is error-free, stop using the old system and transfer to the new one.

This sequence allows better testing and smooth switching without having to cope with many problems ("bugs," human resistance, lack of experience) in a short and crucial period of time.

Another decision that must be made concerns which version of MRP to choose: "net change" or "regenerative" system. The final output is going to be the same, but the EDP problems encountered in the net change system are much more complicated. It requires keeping old schedules and their back-up files, generation of new files for the updated production schedule and, finally, their comparison. In addition to the fact that this data processing is more complex, special attention is also required any time changes are made to files or programs. This makes the system more sensitive to "bugs"--a highly undesirable state of affairs.

Another subject which should be analyzed at this time is the introduction of advanced data base management systems. Traditional information management is based on keeping many

dedicated files of data related to specific subjects such as inventory status, finance, production schedules, statistical files or personnel records. That concept simplifies managing each individual subject but creates duplications in information reported and held, which usually results in conflicts. On the other hand, the new concept is to have one comprehensive data-base holding all interrelated data. There are special software packages which support maintenance of data bases (IMS, IDMS, TOTAL, ADABAS and others) and using them may help to create a sound basis for a good MIS (Management Information System). The planning period before transition to MRP is a very good time to investigate the possibility of moving to one central data base. The reason is that MRP needs well coordinated files of inventory status, production schedules and bills of materials.

As mentioned earlier, the MRP system needs very accurate and consistent files requiring a very careful processing of data (especially the BOM) before operations begin. Since a similar process is required when converting to a modern data-base, it is recommended to combine both into one step and make sure that the conversion is done carefully and completely.

A very important factor which must be kept in mind during the whole process is the human factor. Implementation of an MRP system is going to affect the users of the system (inventory managers, production managers and other functions) and the ones who are responsible for implementation (EDP

and others). Those people must be involved in the process, asked to contribute, be trained in system operations and be made to feel a part of the system. The system may require changes in working habits and procedures and their cooperation is essential for success.

G. CONCLUSIONS

The discussion so far has addressed a pure MRP system. But does it exist in a real life situation? Pure MRP is unlikely in a real situation. There are only a few organizations where the MRP system will be able to cover all materials used. Since the others must also be managed somehow, a compromise must be found between traditional methods and this one. That combination is necessary especially in organizations whose work is not pure production, even though the work may be of a repetitive nature. This can be the case of a shipyard or a repair facility which also produces some items.

The nature of repairs is that there is not an accurate "Bill of Materials" for repair of a given item, although averages and standard deviations may help represent the case as "pseudo-production." This is particularly true about inexpensive spare parts (bolts, nuts, fuses or other "consumables") which have a high total demand, but also high deviations in requirements for repair of certain items.

The best way to act in such an environment is to combine MRP with the regular EOQ models. This will require classification of items according to the system which is used to

control them. Items which are inexpensive and "high-movers" can be controlled by the simple EOQ model, whereas more expensive items, which are not common to many systems and have low (and discrete) demand, can be treated by the MRP system.

It may appear that this combination is more complicated, but it turns out that the input required for MRP already provides the input for the simple EOQ model and the overhead from having another module is overridden by the extra benefits that the combination gives.

III. SUPPLY SUPPORT OF NARF ALAMEDA

The intent of this chapter is to describe the "present" supply support of NARF Alameda, the concept that underlies this system, the data-base and computer resources used in this process, the weak points of the system and elements that require improvement.

Phase II of the San Francisco bay area SER is now underway and it is somewhat difficult, however, to be exact in this description of the "present" system because of the consolidation and the continual changes resulting from it. There will be an attempt to distinguish between activities which existed prior to consolidation and those resulting from consolidation. If everything goes according to the original schedule [7:19], the present system with temporary, pre-NISTARS improvements, will last throughout April 1981.

Figure 4 depicts both pre and post consolidation requisition channels of NARF Alameda and provides a framework for the description to follow.

A. CONCEPT AND OPERATION

The concept applied for the supply support of NARF Alameda is the Area Support Concept [9:III-15]. This concept is generally employed in geographical areas surrounding NSC's and NSD's where the customer activities are nearby. According to this concept, the customer--in this case the NARF--does not

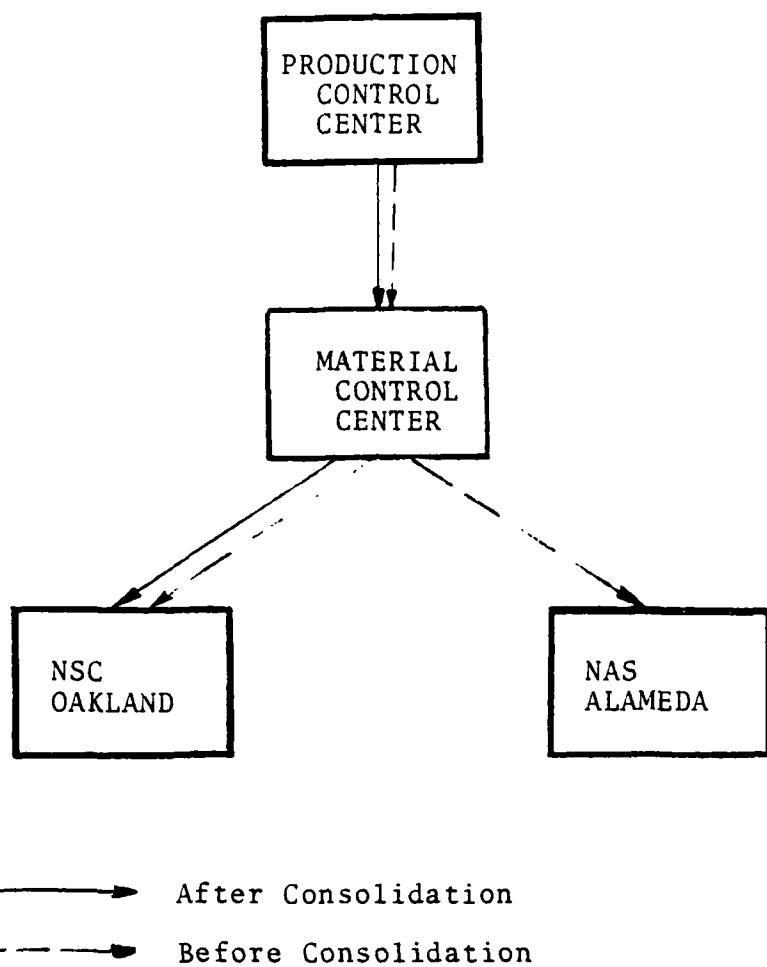


Figure 4: NARF's pre/post consolidation requisition flow

stock items [9]--except nonstandard items or expense item material--and whenever items are needed they have to be requisitioned through the requisitioning channels.

1. Pre-Consolidation Support

Prior to the consolidation, the NARF shops had three sources of supply:

- a. The NARF's NIF (Navy Industrial Fund) Stores.
- b. NAS Alameda--for aviation items.
- c. NSC Oakland--for other items.

Each of these sources has different stocking policies and procedures to determine the items to stock, order quantities, and reorder points.

a. NIF Stores Items

Items stored in the NARF's storerooms are determined by the NARF's material planning personnel. However, approval for establishing items in the Alameda stores is restricted to material section heads or higher. The material planners are allowed to establish NIF stores items with minimum demand frequency of six per quarter and maximum unit price of \$25. Order and reorder quantities are determined by the material planner using his experience and the technical data (drawings) available.

A major portion of the material support for the industrial operation is provided by the Pre-Expended-Bin (PEB) operation. It contains high usage, low-priced items that have been expended from stock records and charged to overhead at the NARF. The NARF also maintains physical

records of materials provided by customers for use on their own jobs.

The NIF Store operation is basically a manual operation. As a result, there is not any (recorded) historical demand data to be used for more intelligent demand forecasting or inventory control. This is going to change with the introduction of the Naval Air Industrial Material Management System (NIMMS) that will be described later on.

b. NAS Alameda

Before the consolidation, NAS Alameda supported the NARF as a wholesale customer for IR Cog material and as a retail customer for the 9 Cog and SPCC managed items. The wholesale stock levels were maintained by ASO. Unfilled NARF requirements were transmitted to ASO for referral, procurement or other action as required.

On the other hand, the NARF's demand for retail material was provided for by the VOSL (Variable Operating and Safety Level) model. The disadvantage of VOSL in this case is that it uses historical demand to forecast future requirements. In reality, NARF demand is dependent on the production schedule of the NARF. For example, during the second quarter of FY '79 the Point of Entry (POE) supply effectiveness (i.e., the ratio of requisitions that were filled and the total number of requisitions entered into the system) of NAS Alameda was 53.2 percent for IR Cog expense items, 74.4 percent for 9 Cog items and 55.7 percent for SPCC managed items [21]. These low figures appear to be a result of the model discrepancy, as described above.

c. NSC Oakland

NSC Oakland was NARF Alameda's source of supply for the 9C, 9D, 9G, 9N and 9Z Cogs. NSC Oakland is a Specialized Support Depot (SSD); that is, an activity with a specialized mission as to the type of material or scope of support. Its stock replenishment is centrally controlled by the cognizant Defense Logistic Agency (DLA) Item Manager (IM). Stock replenishment is based on historical demand.

Similar to the situation at NAS Alameda, this policy does not seem to fit the case.

2. Post-Consolidation Support

Phase II of the consolidation (administrative consolidation) is currently being implemented after phase I (planning) has been completed. Its most significant effect is the fact that NAS Alameda no longer supports the NARF, and the only external source of supply is now NSC Oakland. It also becomes the replenishment source for the NIF Stores inventory.

As mentioned earlier, this period is an intermediate period that will last until the installation and integration of the NISTARS at NSC Oakland and ASKARS at NARF Alameda.

a. NIF Stores

The consolidation has no direct effect on the NIF Stores except that their stock replenishment will be now only from NSC Oakland (NSCO) and not from NSCO and NARF Alameda. However, the implementation of NIMMS requires the appropriate interfaces to NISTARS and ASKARS so that savings from the improved control and usage of recorded data would not be

degraded by additional work (caused by old processes) when items are replenished, stocked or retrieved.

The NIMMS software package is designed to process inventory transactions and does this through an Inventory Balance File and a Transaction file. Those files are used to produce management reports, especially the "NIF Retail Store Stratification" report in which reorder levels are updated, and the "Automatic Replenishment"--which uses those levels and the on-hand quantity.

The function of automatic replenishment requires an interface to ASKARS and NISTARS, to obtain information on the requisitions' status in order to determine when replenishment is required, and later, to direct the material for stocking in ASKARS.

b. NSC Oakland

The change in the organizational structure by itself would not improve the availability of items required by the NARF. In fact, there are many items that were not carried by NSC Oakland before the consolidation and will have to be carried afterwards.

Items for the NARF will be separated from the regular NSC stock (sometimes physically and sometimes only logically) into a Ready Supply Store (RSS). The range and depth of the RSS stock will eventually trade the actual demand instead of forecasting demand only according to historical demand. The actual demand will be forecasted by the MRP model using the BOM information and the production schedule.

The implementation of RSS and MRP concepts will take place in three phases:-

1. Establishing the RSS and its initial stock levels, as described below.
2. Change RSS operation to level settings by "temporary" MRP.
3. Approval, implementation and operation with the proposed MRP system.

Since the temporary MRP data base and software were not ready on 11 November 1979 (the day of establishing the RSS) a "rule of thumb" was used [19] to determine the initial RSS stock. The procedure to set those levels was as follows:-

1. Identify all customer orders that will be worked in FY '80.
2. Generate a list of "candidate" NIIN's by searching the NARF's POE demand for those customer orders in the last three quarters.
3. Delete from the list any NIIN that does not belong to one of the following Cogs: 9Z, 9N, 9G, 9D, 9C.
4. Add items for the following four special support programs: F62 engine, TF34 engine, 50K-17 engine and A6E aircraft.
5. For all items in that list, compute the NAS Alameda protected quantity (stock to support the NARF and squadrons for one quarter, computed by VOSL).
6. Split the protected quantity: 85 percent for NARF and 15 percent for retail protected quantity. These percentages were determined by the share of the NARF's requisitions out of all requisitions filled by NASA.
7. Compute the initial RSS quantity for the item as the maximum of 0 and the difference between the NAS Alameda on-hand balance and the retail protected quantity.
8. Write an AOA ("fill or kill") requisition automatically for all items with a positive initial RSS quantity (for that quantity).

The reasons for using that simple procedure were mainly the short time available and the "need" to prevent its decapitalization to DLA owned stock at NSCO. It also saved a lot of time by generating the requisitions by software and not manually.

The introduction of the RSS required changes in the NARF's requisitioning procedure to NSC. Instead of merely submitting a requisition to NSC, the NARF now has to first determine if the item is available from the RSS stock. If so, the requisition will be directed to the RSS; otherwise, it will be referred directly to NSCO wholesale stock. A terminal communication network allows on-line inquiries against both RSS and wholesale stock.

The integration of the temporary MRP system will occur gradually as that software and data base are expanded. The requirements for the second quarter of FY80, generated by MRP, will cover only the F/E and engine programs. The requirements for the other programs will be determined manually and added to those generated by MRP. Afterwards, the requirements for the third quarter of FY80 will be generated by MRP for all programs. These requirements will be checked and updated manually by the material planners before submission to NSC Oakland.

The process of determining and submitting requirements to NSCO can be further improved with the implementation of the proposed MRP system.

B. AUTOMATED DATA PROCESSING OVERVIEW

As described earlier, prior to the consolidation both NSC Oakland and NAS Alameda were involved in supply support of NARF Alameda. One of the implications of having two "suppliers" was that both activities had to carry out similar inventory management functions, i.e., both activities had to process separately the same kind of transactions and maintain the same kind of files, both referring to the same customer--NARF Alameda. Both NSC Oakland and NAS Alameda use the same inventory management system: the Uniform Automated Data Processing System--Stock Point [UADPS-SP]. After the consolidation, NSC Oakland becomes the only direct supplier for the NARF.

With respect to data processing, it means that NSCO's data processing department will do most of the data processing of data relating to the NARF. However, in addition to processing done by NSCO, there will be some inventory management data processing by the NARF itself. This may involve running the MRP application and generating the requirements to be submitted to the NSCO.

This section describes NSC Oakland's data processing systems. Details on data processing and DP equipment at NARF Alameda are given in the chapter describing the temporary MRP application.

1. Data Processing Equipment and Applications at NSC Oakland

NSC Oakland is one of several of the Navy activities using the Uniform Automated Data Processing System--Stock

point (UADPS-SP). UADPS-SP is the standard software package used by Navy stock points to carry out the various inventory management functions. However, inventory control is only one of the applications run by NSCO's Data Processing Department (DPD) as UADPS-SP. The major applications are the following ones:-

1. Inventory Control.
2. Requisition Control.
3. Financial Inventory Control.
4. Stores Accounting.
5. Civilian Employees Payroll.
6. Supply Overhaul Assistance Program.
7. Labor/Cost/Allotment Accounting.
8. Procurement and Procurement Accounting.

The list of applications is so long mainly because UADPS-SP was developed during the early 1960's, and although it underwent several improvements and modifications, the system is still using concepts and equipment from that period. As a result, instead of having one integrated system, the "system" is composed of a set of related applications that use many traditional files (as opposed to an integrated data-base and a data-base management system), many old-fashioned programs and processing runs and a variety of data processing equipment. Appendix A gives a list of selected UADPS-SP files which, as mentioned earlier, are only part of the data-base.

In addition to the above list of applications, the DPD runs also a telecommunication system. The network has

terminals in the San Francisco bay area and at other Navy facilities, and provides inquiry services relating to inventory and requisitions and data-entry for material storage/receiving and for procurement.

The hardware consists mainly of a dual system: a Burroughs B-4800 CPU and a Burroughs B-3500, a peripheral switching unit that helps sharing the peripheral devices by both CPU's and thereby improve their utilization. The B-3500 is used with a front-end processor (Burroughs B-874) for communication, whereas the B-4800 handles the batch-processing applications. The non-inventory control applications are handled by a Honeywell H200 computer, a Wang computer and an IBM 360/20 card-system. Most of the terminals used in the communication network are Burroughs products (TD-800, TD-700, TC-500). Until recently some non-Burroughs terminals were also connected to the network (Zentec and Hazeltine). The system also includes three line printers, two card readers, two card-punchers and a variety of conventional equipment.

The DPD operates in three shifts, seven days a week and, according to the DPD director, the equipment is utilized to 90 percent or more of its capacity. The major implication of this fact is that it is very difficult to add new applications to the system and also that equipment failures can generate severe backlogs in the system.

Another import aspect of the operation of the DPD is that it usually does not develop its own software.

Only applications that are simple and local in nature are written by local programmers.

2. The Inventory Management Subsystem

The UADPS for stock points is divided into three subsystems, each consisting of one or more applications and each serving a logical group of stock point functions. The three subsystems are:-

1. Activity Management (Designator A).
2. Inventory Management (Designator I).
3. Data Processing Environment (Designator D).

The highest level of interface between the functions performed at a stock point and the UADP System is at the application level. In UADPS terminology, the term "application" is arbitrarily used to define those data processing actions which supplement the manual actions necessary to carry out a given function. Consequently, what is usually referred to (not in UADPS) as inventory management (application) is in UADPS terminology a subsystem and is composed of several applications.

Each application is subdivided into a variable number of operations which are defined as one or more ADP runs performed to produce a given major product or result, e.g., produce a given report, process a specific type of transaction, etc. The large numbers of applications and operations, and the fact that those operations are scheduled manually, explain why it is so difficult to run the system.

The following applications comprise the inventory management subsystem:

1. Customer Information (designator IA) involves the actions required to provide information of any nature to customer activities.
2. Receipt/Due (designator IB) involves those actions beginning with the establishment of a due-in through receipt of proof of storage.
3. Issue/Demand Processing (designator IC) begins with the receipt of demand document and continues through the preparation of a referral order or issue document/picking ticket and proof of issue.
4. Inventory Control (designator ID) includes manipulation of demand data to set stock levels, determining replenishment requirements, reconciling replenishment back order requests, and processing replenishment documents.
5. Quality Control (designator II) involves stock record accuracy, including location audit, physical inventory and physical inspection of stock.
6. Disposal (designator IM) involves computation of excess quantities and follow-up on disposal and/or shipment of excesses.
7. Automated Ready Supply Stores System (designator IN) involves the supply and financial management and recordkeeping functions for RSS. NARF Alameda's MRP system will have to interface with this application.
8. Records Maintenance (designator IP) involves those actions necessary to maintain accurate mechanized records.
9. Repairables Management (designator IR) involves the actions necessary to induct NRFI (Not Ready for Issue) material into a repair facility and to maintain control throughout the repair cycle.

3. Data Files

The inventory management subsystem uses and updates most of the files in the data base. Of special importance are the Master Stock Item Record (MSIR) file and the files which contain customers' requisitions: the Requisition Status File (RSF) and Demand History File (DHF).

The MSIR is a variable length, direct access record containing stock status data for each item carried in stock at the activity. Data elements relevant to identification, control, storage, and quantities of the item are stored in a header record. As stock data accumulates (demand history, demand frequency, due-in quantities and others), it is added in the form of trailers. The access key to the MSIR is by Federal Item Identification Number (FIIN).

The RSF contains randomly stored records of customers' requisitions (stored and accessed by document number) and of the supply action that has been taken by the stock point to satisfy the requisitions. The RSF covers the most recent three months.

The DHF contains the same kind of information as the RSF but covers the previous six months. Records that are deleted from the RSF are transferred to the DHF.

The various operations that comprise the inventory management subsystem are run on various frequencies from daily runs to weekly, monthly, quarterly and annual runs. The files are updated on a daily basis although certain updates occur less frequently. An important disadvantage in the design and in the way the system is run is the fact that many different programs (operations) update the same files. This makes it very difficult to control the system, to ensure the correct sequence of file updates and, especially, to reproduce a previous state of the system files in case of a bad file entry or detection of a software error after the faulty program was used for a while.

4. UADPS and MRP

From the discussion thus far, it should be clear that UADPS and the MRP applications have two different sponsors. UADPS is run by NSC Oakland whereas NARF Alameda will develop and benefit from implementation of MRP. However, since vital information is available at NSC Oakland's DPD and since it will do the computerized inventory management of the inventory reserved for the NARF (in the RSS's), it is necessary to establish an appropriate interface between the systems.

The areas in which the UADPS and MRP systems need coordination and/or use the same data are:

a. Inventory Status File

MRP needs an inventory status file for determining requirements and for other data elements on each item (such as lead time). This information is contained and updated in the MSIR.

b. Bill of Materials

Since maintenance work involves variable quantities of components for doing the same work, the bill of material file of an MRP system has to be created and updated according to historical usage rates of components, when doing specific jobs. Computing usage rates involves identification of the quantity of items that were repaired/produced on a specific job order, and the components that were required to accomplish the job. The first piece of data is available at the NARF whereas usage information is contained in the requisition files--both RSF and DHF.

c. RSS Stock Levels

One of UADPS's functions is to set and update stock levels for RSS. UADPS uses the historical demand as the basic data for setting those levels. It will be necessary to override the "regular" level settings by the requirements generated by MRP.

These problems will be further addressed in the next chapter.

C. EVALUATION AND CONCLUSIONS

The Area Support Concept employed in support of NARF Alameda provides a significant advantage because of the centralized management, stocking and procurement of supplies ("economics of scale"). However, the common method applied to forecast demand may have an adverse effect on the effectiveness of supporting the NARF. The VOSL model assumes that demand in the future will behave the same as in the past but that may not be the case for the NARF because its material requirements are driven by a production schedule which varies from one quarter to another. This problem can best be solved by employing the MRP model.

The NIF store's inventory is and will continue to be managed by a totally different system. The fact that the items carried in the NIF stores are fast moving, low cost items seems to suggest their exclusion from the MRP system at least at the beginning. Also, the fact that their demand is more stable justifies the use of a conventional model.

However, the time may come when the MRP system will be sufficiently reliable, when it may be more cost effective to have only one system for managing the NARF's material requirements. Including this inventory in the MRP system will require adding these items to the BOM file.

As to ADP, it seems that NSCO's DPD may not be the activity to run the MRP application. The out-dated equipment and the large variety of applications that are presently run seem to be sufficiently complicated to manage so that perhaps the NARF should run the MRP system and provide the end results--namely, the material requirements and RSS stock levels, to NSCO's DPD. However, possible incompatibility of the Burroughs equipment at NSC with the NARF system may require appropriate transformations of data to allow use of information maintained by NSCO (MSIR information and recognition data) in the NARF system.

IV. THE TEMPORARY MRP APPLICATION¹

When the idea to implement MRP at NARF Alameda was proposed, it seemed that before doing the full-detail design of the application it would be appropriate to carry out an experiment in which the MRP technique would illustrate the extent to which it could actually forecast the NARF's material requirements. But, as people got more involved in the subject and obtained a better understanding of the work involved, the 500 Department (the department in charge of this application) decided to redefine the objective to design the implementation of a simple MRP system that would take a short time to implement, would be capable of demonstrating the technique for the purpose of comparison with the present system and would provide operational generation of NARF's material requirements until ASKARS and NISTARS are installed.

It was realized that there is a trade-off between simplicity, required effort and the length of the implementation period, and the quality of the results. Unfortunately, the NARF's regular personnel had to carry out the project with almost no additional people (their mission does not include software development!); the short time available made all other alternatives infeasible. It is believed, however,

¹Based on personal interviews and discussions with LCDR W. P. Benefiel, from NARF Alameda.

that even this "low quality" product will produce a supply effectiveness better than that of the present system.

This chapter describes the "temporary" MRP application, the functions it performs, the data-base and software modules, the creation of the initial data-base and the interface to UADPS and NSC Oakland.

A. SYSTEM OVERVIEW

The temporary MRP application was developed and is run on the ADP system of the production planning and control department (500) at NARF Alameda. The system consists of a PDP 11/70 CPU with an IAS (Interactive Application System) general purpose operating system, 512 KB memory, 2 RP06 300 MB disk drives, 1 RS04 swapping disk, 2 TE16 tape drives, 1 LPU line printer, 1 CRU card reader, 28 hard wired terminals and some other "dial-up" terminals. This system is used to run several local NARF applications and can easily handle the MRP application.

The major objective of implementing the temporary MRP system is to generate a forecast of the NARF's quarterly material requirements. These requirements are to be used as stock levels for the RSS.

Secondary objectives are to provide the NARF's material planners with accurate data that will assist them in doing their job, especially when ordering materials for unscheduled jobs. The system is also to provide some exception reports

on consumption of materials to allow analysis of these jobs and the reason for the exceptional consumption.

The system produces three major outputs:

1. Material Requirements

These are only recommendations. They are checked and updated by the material planners if they do not agree with the systems recommendations.

2. Answers to Queries

The system provides a set of queries on the BOM file and the gross requirements forecast. This information is used routinely by the material planners.

3. Bill of Material Listing

The listing is designed to provide the same basic information as the queries but requires the material planner to do the material requirements computation manually. The report is used as a back-up to the communications network and also for those material planners that do not have a terminal.

The inputs to the system consist of requisitioning data from UADPS and induction data (quantities of items reaired) from NARDAC (Navy Regional Data Automation Center) that are used to update the BOM file and the workload schedule from ASO which is later used to translate the schedule into requirements. Another input is the information that relates IIC's (Item Identification Codes) to FIC's (Family Identification Codes) which is required for translation of the workload schedule--which is by FIC's--into a schedule

by IIC's. The inputs to the system are all external data although it is originated by or refers to the NARF.

A major element that is missing in this MRP application is the inventory status file which has to be used for determination of net requirements. The reason for that is that this application is used only to determine gross requirements which are needed as RSS stock levels. Therefore the computation of net requirements does not have to take place in this system but rather in UADPS-SP.

The environment in which MRP is run includes both time-sharing and batch processing. The requirements generation is run on a quarterly basis. The run includes first an update of the files and later the generation of the outputs. This fact raises some questions about the need for on-line inquiries. But it turns out that, since the equipment was already there and was underutilized, it would be nice to provide this service.

Figure 5 describes the information network and the operation of the MRP application.

B. MRP DATA-BASE

The data-base for the MRP application consists of three master files and two index files:

1. The bill of materials file (BOM) (OSI19.DAT).
2. The workload schedule file (OSI20.DAT).
3. The MRP forecast file (OSI21.DAT).

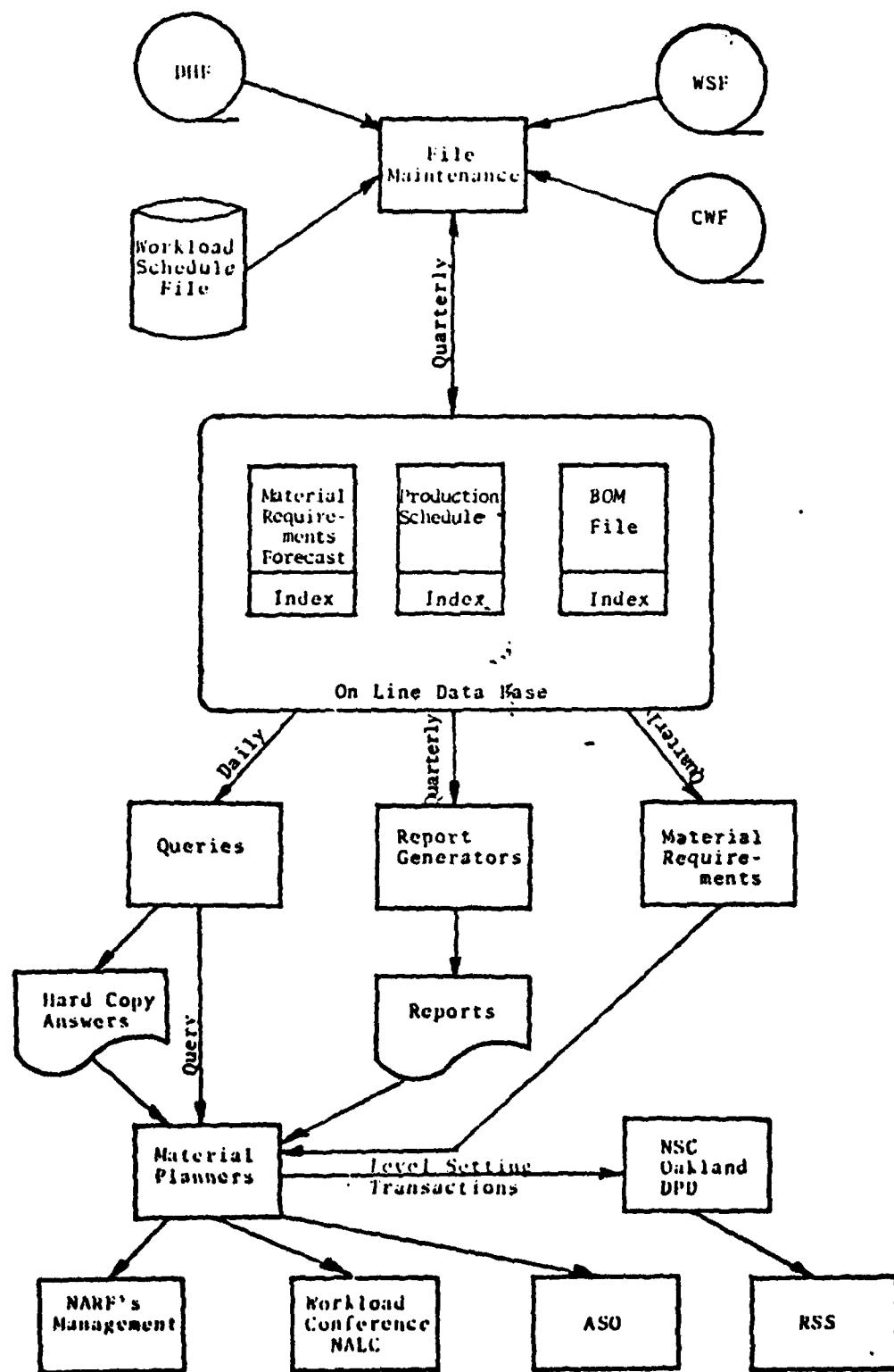


Figure 5: MRP information network diagram.

4. The "BOM" index (OSI18.DAT).

5. Index to MRP forecast.

The BOM file contains information about items required to repair end-items. The file is a direct access file (access key is the IIC of the end-item) and contains one header record and several data records for each end-item (IIC). Both header and data records have fixed lengths. The header contains information about the end-item and summary data about the consumable items required for its repair, total cost of consumables for repair of one IIC and the total number of the end-items that were inducted in the past.

The data record (one for each consumable per end-item) contains the information as described in Table I.

Figure 6 describes the header layout.

IIC 1-4	Ø 5	FIC 6-9	NSN 10-22	COG 23-24	Total Cost 25-28	IIC Induction Qty 29-32

Figure 6: BOM header-record layout

Access to the file is based on a pointer to the beginning of the header, read from the BOM index file. The header is used, and then (data) records are read sequentially. The first character is checked and if it is other than "1" it is assumed that the end of the IIC has been reached.

TABLE I
The Data Record

Columns	Description	Data Type	Comments
1	Filler	Char.	Decimal Digit 1
2-14	NSN	Char.	
15-16	COG	Char.	
17-18	U/I	Char.	
19-20	Planner & Estimator Code	Char.	
21-24	Qty (total)	Integer	Required for Qty in header
25-28	Unit price	Real	
29-32	# of reqn's	Integer	Whose total Qty is in 21-24
33-36	Qty per unit*	Integer	Max. Qty per 1 end item
37-38	U/I of Qty per unit*	Char.	In case it differs from that in 17-18
39-40	Essentiality*	Char.	"KE" or "NE"
41-44	Replacement factor*	Real	
45-48	Qty (Qtr 1)	Integer	
49-52	# of reqn's (Qtr 1)	Integer	
53-56	Qty (Qtr 2)	Integer	
57-60	# of reqn's (Qtr 2)	Integer	
61-64	Qty (Qtr 3)	Integer	
65-68	# of reqn's (Qtr 3)	Integer	
69-72	Qty (Qtr 4)	Integer	
73-76	# of reqn's (Qtr 4)	Integer	

*The data is extracted from the Weapons Systems File (WSF) maintained by ASO.

The information for each IIC contains data from the most recent four quarters. The totals are kept, and an average (total quantity/quantity inducted) is computed in specific application programs.

The workload schedule file is a sequential fixed length record file, created especially for the MRP application. It is created by typing in (using an interactive data entry program) the workload schedule received from ASO. The schedule is by FIC (Family Identification Code), as opposed to the BOM file which is by IIC. Figure 7 describes the layout of a workload schedule record.

FIC	NSN of FIC	Workload Qty Scheduled	Standard Repair Hours	Responsible Shop	Program
1 - 4	5 - 17	18 - 20	21 - 26	27 - 30	41

Figure 7: Workload schedule record layout

As seen from Figure 7, the file also contains information that is not necessary for MRP--the standard hours for repairing the scheduled quantity. Before MRP was initiated, there was no other file that contained the production schedule and repair standard hours and because it was very useful (for other functioners in the NARF) to have them, they were added to the records.

The MRP forecast file contains the consumable NIIN forecast for each end item (IIC). These, in fact, are the

gross requirements before they are summed to give one quantity for each NIIN. This file is used for two main purposes:

1. Provide data for the material planners for planning purposes (answers to queries).

2. Record changes made by the material planners to the gross requirements generated by MRP. Those gross requirements are subject to inspection, changes, deletions and additions made by the material planners, and this file contains the last (best) version of the requirements forecast.

The file is a direct access file and consists of fixed length records; each record representing a consumable NIIN required for a FIC/IIC. The data is grouped in a hierarchical order: the highest level is a FIC, then IIC, and then a consumable NIIN. All data for one FIC is co-located and subdivided into IIC's that comprise that FIC. Within an IIC are all consumable NIIN's required for the repair of the IIC.

Figure 8 describes schematically the structure of the file. Figure 9 describes the record layout of the MRP forecast file.

The BOM Index file is, as its name specifies, the index to the bill of materials file, and in addition, it also contains the information that is used as the "translation table" of the composition of each FIC by IIC's. This is achieved by keeping the total quantity inducted by FIC and the specific IIC quantities that comprise that quantity. Dividing the IIC quantity by the total (FIC) quantity gives the relative frequency of the IIC and allows for the

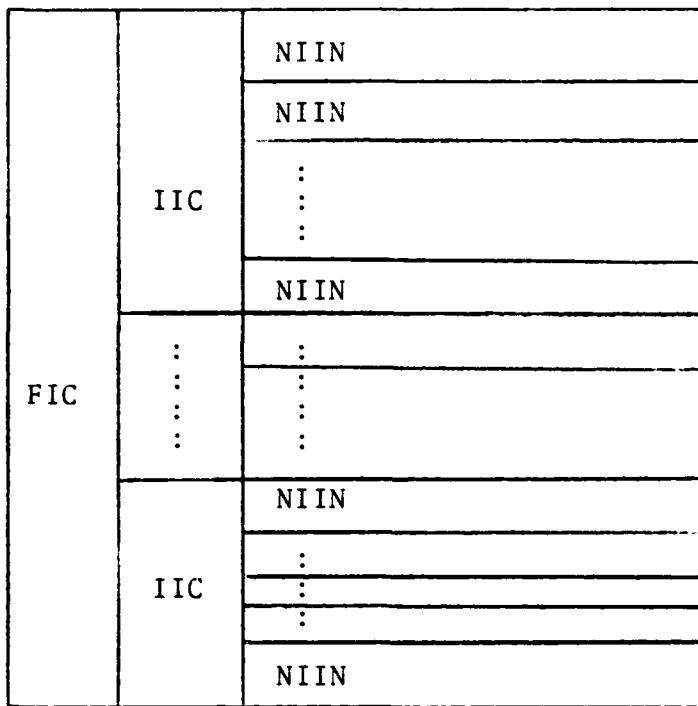


Figure 8: Schematic Structure of MRP Forecast File.

← end item → "Consumables" data →

FIC	IIC	NSN	COG	U/I (F8.2)	Forecast MRP Qty (I6)	Extended price per consumable (F 10.2)
1-4	5-8	9-21	22-23	26 - 33	34 - 39	40 49

NSN of IIC 50 - 64	NSN of FIC 65 - 77	Responsible Shop 78 - 81	Work Standard 82 ^(F6.1) ₈₇	Program 88	Work Schedule for FIC (I3) 89 - 91

Figure 9: MRP Forecast File Record Layout.

subsequent translation of the workload schedule from a FIC schedule to an IIC schedule.

This index file is used by various application programs to access the BOM file and its small size allows the whole file to be loaded into memory when needed.

The file contains five different types of records. A Type 1 record contains two fields: FIC and the starting location of IIC location records within this file. There is a single record per FIC and each contains a pointer to the location of the corresponding IIC's.

The Type 1 records are delimited by a Type 2 record which simply contains the four characters "END*".

Following the Type 2 record is a group of Type 3 records --one record per FIC, each record containing "####" in the first four characters of the record (an identifier) and then the FIC quantity of total inductions and the FIC itself. This is the data used for the translation of FIC to IIC's and could, in fact, have been stored in the Type 1 records.

Type 4 records contain the actual pointers to IIC locations in the BOM file. Each record contains the IIC, IIC induction quantity (for translation), starting BOM location and ending BOM location for this IIC. The Type 4 records are grouped so that all IIC's belonging to one FIC are together, and the starting location of this group is being pointed at by a Type 1 record.

A Type 5 record contains "####" and "0000" and marks the end of the file.

The Index to the MRP Forecast file is a regular index file allowing access to the master file by different keys: IIC, FIC or NSN.

C. SOFTWARE

The temporary MRP application consists of the following modules:

1. File maintenance
2. Queries
3. Requirements generation module.

File maintenance is the set of application and utility programs that are used to update the BOM file. As described in the previous section, there is no update of the production schedule file.

The principle behind updating the BOM file is to advance the information regarding the second, third and fourth quarters by one quarter forward (thereby deleting the "oldest" quarter), and then insert the information regarding the past quarter into the fourth quarter's location. The file that contains the BOM information from the past quarter is created independently and is used later as one of the inputs to the program that creates the new generation of the BOM file. The same process was utilized in creating the initial BOM file. All that is necessary is to stop after creating the file with the most recent data (on the first run, it is the only data) and use the output as "the" BOM file.

The steps that comprise the file maintenance process are as follows:

1. Create (by a simple data entry program) a direct access file of all customer orders that have been used during the last quarter.
2. Using this file as a table, extract from the Demand History File all records that contain customer orders that are in the table. (Note: The customer order contains the IIC.)
3. Sort these records, which are in fact consumption data, by IIC.
4. Construct the "induction data" file containing for each IIC the total quantity inducted during the last quarter. Sort the output by IIC.
5. Use the induction data and the consumption data (both sorted by IIC) to create the one quarter BOM file. The same information is used to update the FIC to IIC "translation table" that is contained in the BOM file.

Figure 10 describes the file maintenance run.

The Queries are programs designed to assist the material planners in their work. There are dynamic queries in which the planner can change the information in the file he is querying as opposed to "static" queries in which the information is only presented.

The "static" queries include the following:-

1. Inquire BOM by FIC. This inquiry displays all data (with appropriate headings) about the FIC.

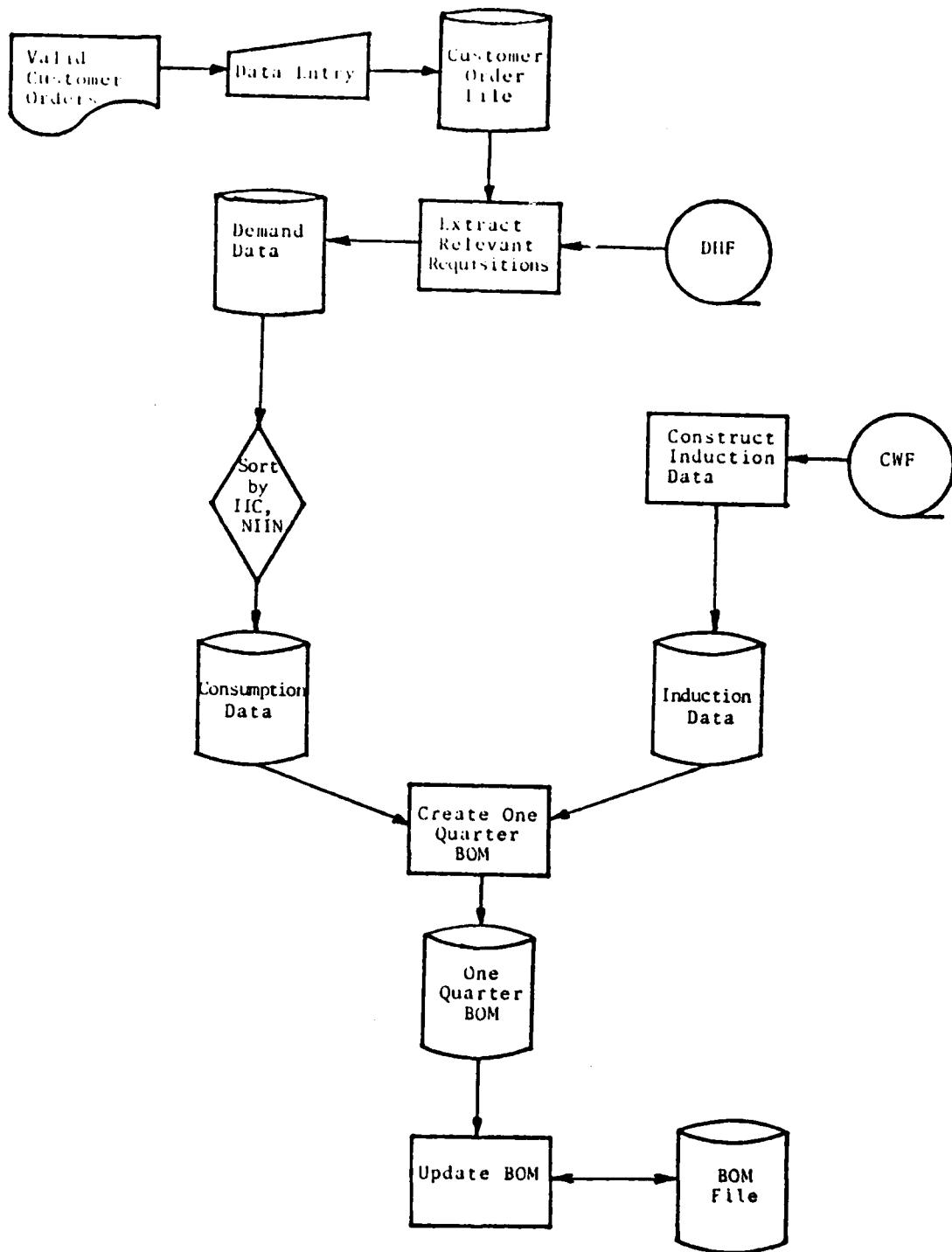


Figure 10: BOM file maintenance run.

2. Inquire BOM by IIC.
3. Inquire MRP forecast by the following pairs of parameters:
 - (a) \$ value/shop
 - (b) \$ value/IIC
 - (c) \$ value/FIC.

The \$ value refers to the value of the consumable items.

Such a query will list all consumable forecasts for end items/shops whose \$ value is greater than the threshold specified in the query. The information about each end item is presented separately.

4. Inquiry by a variable threshold of \$ value of consumables value.

Here the planner specifies a value threshold and gets, in return, all NSN's whose value is greater than the threshold specified. This allows the planner to concentrate on the most expensive items first, and then on the other items.

The "dynamic" or interactive inquiries refer to the MRP forecast file and are intended to use the material planner's knowledge in order to get a "better" forecast. The planner inquires the file by NSN (of consumables) and thereby gets sequential access to all IIC's that include that consumable. After having the information displayed, the planner can (by using appropriate codes) make additions, deletions or changes in the forecast of the requirements for that specific IIC.

The Requirements Generation is the heart of the application and concludes the whole process. This phase has two separate steps:

1. Creation of the MRP forecast.
2. Creation of the transactions for the RSS stock replenishment.

The MRP forecast is generated by computing an average requirement for each IIC (total consumption during four quarters divided by total end-item inductions) and then multiplying it by the quantity of that IIC scheduled for induction during the coming quarter. The IIC induction quantity is computed from the FIC schedule by multiplying the FIC quantity by the relative frequencies of the IIC's composing the FIC. This forecast is used to load the file which will be used by the material planners.

After the material planners have finished their changes, the next step is to sort the requirements by NSN (of consumables), sum them for each NSN and write a transaction to an output file; this file contains the NSN and the total quantity. This quantity will have to be in the RSS at the beginning of the quarter (or shortly after it) to ensure smooth operation of the NARF according to the production schedule.

D. INPUT, OUTPUTS AND PROCESSING

The inputs to the MRP application are mainly the outputs of the UADPS-SP. These include the demand history file (DHF) from which the NARF's requisitions are extracted, to be used later as consumption data for updating the BOM file, and also the MSIR, from which general information such as nomenclatures,

units of issue, unit price and quantity-on-hand (at the RSS) are extracted.

Another input is the committed workload file (CWF) which contains induction quantities. This file is maintained by NARDAC for the independent production control application. The workload schedule file that was described in the data-base section is, of course, another important input to the system.

The last input is the set of valid customer orders (job numbers) which are entered through an interactive data-entry program and are used as a table for extracting relevant records from the DHF.

All inputs described above, except the MSIR, are originated at the NARF, although part of them (DHF, CWF) finally arrive at the MRP application as external inputs. This is an important factor because it leaves very little control (frequency, data integrity) that can be imposed by the MRP application.

The outputs from the MRP application were also described earlier. They include essentially the transactions for level setting of RSS stock, answers to queries by the material planners and various reports which are generated during the process of file maintenance and requirements generation. In a well developed system, these reports would have been outputs of other applications, but since these do not exist at the NARF, this was an opportunity to produce these products. Examples of these products are a list of customer orders

(instead of a production schedule), summary induction information by IIC, and BOM listings for general use by material planners (as back-up to inquiries).

The MRP application involves two modes of processing. The first is the process of file maintenance and requirements generation which is run once per quarter. The other is the inquiry system, in which files and programs are loaded permanently and used by the material planners.

The file maintenance involves a sequence of events that determines the schedule of the whole process. The first constraint is that the BOM cannot be updated as long as customer orders are still active because the consumption is not complete yet. Customer orders are closed at the end of the second month of the quarter following the quarter for which they were opened; this then is the earliest time for the beginning of the process.

A second constraint is imposed by the determination of the production schedule. This is done in a conference that takes place during the first week of the third month of each quarter, and during the conference the schedule for the coming quarter is determined and a tentative schedule is prepared for the following quarter.

Consequently, the processing goes as follows: The old BOM and the tentative production schedule are used to prepare the background information for the conference (identify critical items required to carry out the schedule). Then, during the first week of the third month, the file maintenance

run is performed making the BOM ready for generation of the gross requirements. The requirements generation program is run in the second week of the third month using the final production schedule that was determined in the conference. The MRP forecast is then loaded for analysis by the material planners who have another week to make their changes in the material forecast. At the end of the third week the final run is made and the transactions are generated and submitted to NSC Oakland. This leaves at least seven days for NSC Oakland to process the transactions and to position the materials in the RSS.

E. EVALUATION OF THE TEMPORARY MRP SYSTEM

A review of the temporary MRP application reveals a number of problems. The first problem relates to the production schedule. Implementation of MRP requires the existence of such a schedule. The NARF does not have an automated production schedule, and the file that is used here is created especially for the MRP run. Consequently, the file is used only for MRP and lacks feedback and updates as the schedule is carried out. Therefore, the possibility of updating the material requirements during the quarter does not exist.

The file maintenance software also involves some problems. The software was designed with simplicity as a goal, thus leaving some areas uncovered. One of these is the update of the BOM file as new jobs appear. Since the only basis for updating the BOM file is actual jobs that have been completed

in the past quarter, there is no way to enter information or estimates about jobs that are scheduled for the first time. This means that the system will not be able to forecast requirements for the whole production schedule, and there will always be some customer orders that will not have materials prepared. This problem is partially solved by allowing material planners to change forecasts, but they do not have the possibility of inserting a whole new item.

Validity checks on input are another problem that is treated only partially. Although most of the inputs come from other systems, there still should be some checks, especially on the reasonableness of material consumption. An analysis of the NARF's requisitions during the period of April 1978 until March 1980 revealed many requisitions for very large quantities, presumably resulting from combined requisitions for more than one customer order, but reported on only one order. If such quantities are not extracted (by some kind of inspection), they may ruin the averages in the BOM file and consequently the whole forecast.

The way the system was developed may introduce a problem after the system becomes operational. The system was designed and implemented by a project officer and two programmers that were especially hired for this mission. The involvement of other people, and especially users, in the NARF's 500 Department was minimal and this means that a special effort will be required to train the users, acquaint them with the new tool, and make them efficiently utilize

the system. The lack of good documentation (because the software was written by people that were hired for a very short period of time) will make that job very difficult.

V. THE PROPOSED MRP SYSTEM

The proposed MRP system is designed to meet the same objectives as the temporary system, i.e., forecast of NARF's material requirements, maintain and update the required data-base, and provide the appropriate interface to the supply-support system. However, the introduction of ASKARS, as well as the problems that have been identified in the temporary system, require and provide the opportunity to introduce some improvements. And that is what the proposed system is intended to do.

The intent of this chapter is to provide a functional design of the proposed system. It should serve as the basis for detailed design and implementation by NARF Alameda people after ASKARS becomes operational.

The implementation of ASKARS raises the following factors, which will become important to the design:

1. New ADP equipment will be installed. In addition, there will be new software and application programs; this requires compatibility between the system on which MRP will be run and ASKARS. A logical solution is to run MRP on the ASKARS ADP equipment.

2. The available time for design and implementation of the proposed system is long enough to prevent short-cuts because of time pressures.

3. The implementation of ASKARS requires professional ADP people.

4. ASKARS' software, and especially the order processing module [22: Enclosure (1), Section 5], has many similarities to MRP. The use of the same or a slightly changed approach in the design of the MRP system will increase the understanding of the MRP system and facilitate its implementation and maintenance.

A major component of the proposed system is the algorithm for generation of the gross requirements. The fact that NARF Alameda performs mainly maintenance instead of production results in an uncertainty about the BOM information. This has been treated only in a minor way in the temporary system. Therefore, a considerable effort is devoted here to develop a better and more accurate algorithm to handle this uncertainty.

Another important area that this system considers is the production schedule and the human resources (professions and standard hours) that are required to carry out the schedule. Since a production schedule file is not in existence at present, a simple application is proposed below. It will satisfy the MRP requirements as well as the basic needs of the production and control people.

Production planning and control was also a major factor in the design of the BOM data structure. It provides the basis for inclusion of other resources in the BOM file.

This may contribute further to a better and accomplishable production schedule. This will not be developed here in detail, but will be outlined for further development in the future.

A. PRM-MRP: PROBABILISTIC REPLACEMENT MODEL FOR MRP

This section is devoted to the development of the proposed model for material requirements planning in a maintenance oriented facility.

1. The Demand Distribution

The demand for an item in a maintenance oriented environment is determined by the following three factors:-

a. The Production Schedule

It determines the end items that will be reworked and thereby determines the set of consumable items that are candidates for consumption. The candidates are the components that make up the scheduled end-items.

b. The Replacement Factors

The replacement factor of a consumable item that comprises a specific end-item corresponds to the proportion of the installed quantity of that consumable item in one end-item that is expected to be replaced/consumed in the course of reworking the end-item. The replacement factor, P , takes on values such that $0 \leq P \leq 1$ where $P = 1$ represents consumables that are always replaced during repair of the end-item and $P = 0$ represents components that are never replaced. The replacement factor is affected by maintenance

policies, experience of the people that do the maintenance, and by the nature of the item and the environment in which it is used.

c. The Demand Distribution for the Item Being Replaced

Let n_1, n_2, \dots, n_m be the installed quantities of a consumable item in m different end items $IIC_1, IIC_2, \dots, IIC_m$, respectively. Let P_1, P_2, \dots, P_m be the corresponding replacement factors of that consumable item and let Q_1, Q_2, \dots, Q_m be the scheduled quantities per quarter for the end items. Let X_i be a random variable representing the demand for the consumable item during the quarter for the scheduled repair of IIC_i . Then, X_i has a Binomial distribution, namely

$$b(X_i; n_i Q_i, P_i) = \binom{n_i Q_i}{X_i} P_i^{X_i} (1 - P_i)^{n_i Q_i - X_i}, \quad i = 1, 2, \dots, m$$

The mean of the distribution is $n_i Q_i P_i$ and the variance is $n_i Q_i P_i (1 - P_i)$. [27:28,69].

Each X_i is an independent random variable because the demand for an item by an IIC is independent of the demand for that item by another IIC.

Consider now the total demand for an item during a quarter. Let it be the random variable X . It follows that

$$X = X_1 + X_2 + \dots + X_m.$$

The mean of X (or expected value of X) is

$$E(X) = n_1 Q_1 P_1 + n_2 Q_2 P_2 + \dots + n_m Q_m P_m = \sum_{i=1}^m n_i Q_i P_i [27:40].$$

Similarly, since X_1, X_2, \dots, X_m are independent variables, the variance of X , $\text{Var}(X)$, is

$$\begin{aligned} \text{Var}(X) &= n_1 Q_1 P_1 (1-P_1) + n_2 Q_2 P_2 (1-P_2) + \dots + n_m Q_m P_m (1-P_m) \\ &= \sum_{i=1}^m n_i Q_i P_i (1-P_i). \end{aligned}$$

The probability distribution of X can be approximated (with continuity correction) by the Normal distribution.

2. The Basic Model

Planning Horizon--Repair schedules are developed on a quarterly basis at the NARF. Additionally, the inventories of consumable repair parts are funded either from the Navy Stock Fund (NSF) if provided and managed by a NSC or by the Navy Industrial Fund (NIF) if purchased and managed by the NARF. Both funds serve as revolving funds which provide a fixed amount of money for a given quarter to buy inventories. Customers are billed for items used and submit payments to these funds. The money collected is returned to the NSC or the NARF at the beginning of the next quarter. Adjustments in the amount of money in either fund is made quarterly or less frequently depending on the variation in the production schedule.

Because of the repair schedule and the nature of the NSF and the NIF, demand for repair parts appears to be independent from one quarter to the next. Therefore, the model

to be presented below will have a planning horizon of one quarter in length and will be what is known in inventory theory as a "single period" model [14: Chapter 6].

Objective--In providing an inventory of repair parts the logical objective is to strive for a maximum availability of each item. If it is known that an item is replaced 100% of the time during overhaul of an end item, then it is logical to stock for that 100% level. The MRP approach will determine the total quantity of such an item easily.

If, however, an item is replaced less than 100% of the time, then stocking that item to the 100% level is going to be wasteful unless future quarters' production schedules are able to absorb any surplus. A surplus at the end of a quarter in absence of knowledge of future schedules results in NSF or NIF money being tied up which could have been used to buy more of some other item either in the upcoming or in the past quarter.

Thus, a balance needs to be sought between the chance of a surplus and the chance of a deficit for the items not replaced 100% of the time such that the remaining funds in the NSF or NIF (after the "100% items" are purchased) are used efficiently.

Objective Function--The balance being sought above will be determined by developing an objective function which describes the expected costs for all the items not replaced at the 100% level as a function of the amount of each item to be placed in the RSS or NIF stores at the beginning of the quarter. The following costs are assumed to be appropriate for this function.

a. Processing Costs

A special processing cost per unit, C_p , which is different from the procurement cost, is incurred to establish an item in the RSS or NIF's stores. If the quantity of an item going into a store is denoted by y then the total processing cost for that item will be represented by the product:

$$C_p y.$$

b. Holding Costs

The space required to store an item being demanded during the quarter must be large enough to hold all y units of the item. A unit cost, C_h , is assumed to be incurred regardless of how long a unit is in the store during the quarter.

The total holding cost will therefore be:

$$C_h y.$$

c. Penalty Costs

Two forms of penalty costs should be considered. The first is a shortage cost for being out of stock at some time before the end of the quarter; the second is a surplus cost for having undemanded units of an item still in stock at the end of a quarter.

In the case of a shortage, a unit must be obtained from outside the store. In the case of the RSS, this unit might be available at the NSC or it might have to be obtained somewhere else in the supply system. In the case of a NIF store it would probably have to be obtained from the appropriate DLA or GSA source. Concentrating on the RSS from now on, we assume a cost of π_1 per unit requisitioned from the NSC and a

cost of π_2 per unit requisitioned from outside the NSC.

These costs should reflect the time delays resulting from having to go outside the RSS. It is reasonable to assume that $\pi_1 \ll \pi_2$.

If demand X for an item exceeds y , the amount in the RSS, then the shortage cost will be:

$$\pi_1[X-y] ,$$

if X is not so large that the stock w at the NSC is also exhausted (that is, $X \leq y + w$). If X is so large that we must go to the outside, then the cost will be:

$$\pi_1^w + \pi_2[X - y - w].$$

In the case of a surplus, the unit cost for having a surplus is assumed to be kC where C is the unit purchase cost and k is a factor which may be greater than 1.0. The cost of a quarter's surplus can be then written as

$$kC[y - X] ,$$

and applies only if $X < y$.

d. Expected Total Costs

If we let $p(x)$ represent the binomial probability that X units are demanded during the quarter for a given item, the expected total cost for the quarter can be written as:

$$\begin{aligned} EC(y) = & [C_p + C_h]y + \sum_{X=0}^y kC[y - X]p(x) \\ & + \sum_{X=y+1}^{y+w} \pi_1[X - y]p(x) \\ & + \sum_{X=y+w+1}^{\infty} \{\pi_1^w + \pi_2[X - y - w]\}p(x) \end{aligned} \tag{1}$$

If the demand is sufficiently large that demand can be assumed to be Normal then

$$\begin{aligned}
 EC(y) &= [C_p + C_h]y + \int_0^y kC[y - X]f(x)dx \\
 &+ \int_y^{y+w} \pi_1[X - y]f(x)dx \\
 &+ \int_{y+w}^{\infty} \{\pi_1w + \pi_2[X - y - w]\}f(x)dx,
 \end{aligned} \tag{2}$$

where $f(x)$ denotes the density function for the associated Normal distribution.

Optimal Order Quantity--The basic model seeks to determine a value for $y \geq 0$ which minimizes $EC(y)$ in either the discrete form of equation (1) or the continuous form of equation (2).

The calculus can be applied to equation (2) to get optimal y . Taking the first derivative of $EC(y)$ with respect to y and setting it equal to zero results in

$$\bar{F}(y) = \frac{C_p + C_h + kC - [\pi_2 - \pi_1]\bar{F}(y + w)}{\pi_1 + kC} \tag{3}$$

where

$$\bar{F}(y) = \int_y^{\infty} f(x)dx$$

and

$$\bar{F}(y + w) = \int_{y+w}^{\infty} f(x)dx.$$

In the discrete case we want the largest value of y for which

$$\bar{P}(y) > \frac{C_p + C_h + kC - [\pi_2 - \pi_1]\bar{P}(y + w)}{\pi_1 + kC} \tag{4}$$

where

$$\bar{P}(y) = \sum_{X=y}^{\infty} p(x)$$

and

$$\bar{P}(y + w) = \sum_{X=y+w}^{\infty} p(x)$$

This results from the analysis of finite differences in which we seek the largest value of y for which

$$EC(y) - EC(y - 1) < 0.$$

In the event that the NSC has a large stock outside the RSS we can assume $w \rightarrow \infty$ and equations (3) and (4) reduce to

$$\bar{P}(y) = \frac{C_p + C_h + kC}{\pi_1 + kC} ; \quad (5)$$

$$\bar{P}(y) > \frac{C_p + C_h + kC}{\pi_1 + kC} . \quad (6)$$

3. Extensions of the Basic Model

The basic model described above did not consider situations where two or more end items are demanding units of the same repair part and where a budget constraint limits the amount of units which can be purchased for each of two or more repair parts.

Two End-Items Demanding the Same Repair Part--To study this case, let X_1 and X_2 be the units of a certain repair part demanded by end items Nos. 1 and 2, respectively. The total

demand X for the repair part is then the sum of X_1 and X_2 ;
namely,

$$X = X_1 + X_2 .$$

The surplus cost term of the expected cost for a quarter is the same form as above, namely,

$$\sum_{X=0}^y kC[y - X]p(x)$$

or

$$\int_0^y kC[y - X]f(x)dx ;$$

except that now $p(x)$ and $f(x)$ are the probability and density function associated with a total demand of X . Since X is the sum of X_1 and X_2 and since X_1 and X_2 are independent random variables we have a density function for X which is approximately Normal as discussed earlier.

The shortage cost term is more difficult to develop. Let us assume that a quarter has a length of T time units and that the supply y of an item is exhausted at t time units after the start of the quarter. It follows that if $t < T$ then a shortage will occur before the quarter ends. Let us also assume that the two end items consume at rates r_1 and r_2 where

$$r_1 = \frac{X_1}{T} , \quad r_2 = \frac{X_2}{T}$$

From knowledge of r_1 and r_2 we can determine t since

$$[r_1 + r_2]t = y .$$

Thus,

$$t = \frac{y}{r_1 + r_2} = \frac{yT}{X_1 + X_2} .$$

The shortage cost function for end item No. 1 will be then

$$\pi_{11}[X_1 - r_1 t] = \pi_{11}[X_1 - \frac{X_1}{T} \{ \frac{yT}{X_1 + X_2} \}] = \frac{\pi_{11} X_1}{X_1 + X_2} [X - y]$$

where π_{11} is the shortage cost associated with getting a unit of the repair part from the NSC for repair of end item No. 1, if the supply at the NSC can meet the total demand. Similarly, for end item No. 2,

$$\pi_{12}[X_2 - r_2 t] = \frac{\pi_{12} X_2}{X_1 + X_2} [X - y] .$$

The sum of these shortage costs is

$$\frac{\pi_{11} X_1 + \pi_{12} X_2}{X_1 + X_2} [X - y]$$

and the expected costs of shortage can be approximated by

$$\int_y^{\infty} \frac{\pi_{11} \mu_1 + \pi_{12} \mu_2}{\mu_1 + \mu_2} [X - y] f(x) dx$$

if the NSC has a very large back-up stock. The terms μ_1 and μ_2 correspond to the mean demand for the individual end items for the given repair part [28].

The expected costs for one repair part used by two end items can be written as

$$EC(y) = [C_p + C_h]y + \int_0^y kC[y - x]f(x)dx + \int_y^\infty \pi_1[x - y]f(x)dx \quad (7)$$

where

$$\pi_1 = \frac{\pi_{11}\mu_1 + \pi_{12}\mu_2}{\mu_1 + \mu_2} . \quad (8)$$

The optimal value of y can be determined from equation (5) if π_1 is that given by equation (8) and $\bar{F}(y)$ uses the distribution of the random variable X where $X = X_1 + X_2$.

More than Two End-Items Demanding the Same Repair Part

Equations (7) and (5) are still applicable when we have n end-items if we use

$$X = X_1 + X_2 + \dots + X_n$$

and

$$\pi_1 = \frac{\pi_{11}\mu_1 + \pi_{12}\mu_2 + \dots + \pi_{1n}\mu_n}{\mu_1 + \mu_2 + \dots + \mu_n} .$$

The model, and the problems associated with providing the data it requires, are further discussed in Appendix E. However, the discussion in the following sections assumes that the necessary data will be available.

B. SUPPORTING INFORMATION

The basic principles of an MRP system and an example of a system that satisfies some of the NARF's needs has been described in previous chapters. Therefore, the material presented hereafter will not repeat all the details and will assume that they are clear.

1. Outputs, Inputs and Data-Base

The outputs of the proposed MRP system are basically the same as those of the temporary system. The main difference should be in the accuracy of the forecast that the system generates.

The system will produce the following outputs:

1. Material requirements forecast.
2. Answers to queries about the forecast and the BOM file.
3. Transactions for RSS level setting.
4. Transactions for updating the ASKARS order processing module.

The additional transactions generated by the MRP system are designed to provide the input to ASKARS that will allow using its existing software for follow-up on the transactions submitted to NSCO from submission until the material is received and placed in the appropriate bins in ASKARS.

The types of inputs to the system and the data-base are the same as in the temporary system. The structure of the files and the fields in the records are different but basically the same kind of inputs are used to maintain similar files. However, there are two differences:

a. The input for maintaining a production schedule will be more involved but will upgrade the quality of the data-base. This subject is covered in detail in a special section on the production control subsystem.

b. The material requirements forecast, which is an output of the system, will also be an input to another program that will use the same information to generate the order processing transactions for ASKARS.

2. Functions

The MRP system will perform the following functions:

- a. Input edit.
- b. Query.
- c. Report generation.
- d. File maintenance.
- e. RSS level setting.
- f. Generation of information for requisition follow-up.
- g. Analysis to identify exceptions (in material usage).

3. Algorithms

Four algorithms are needed for MRP.

- a. Extract data from given files according to required fields/sequences.
- b. Sort files according to required fields/sequence.
- c. Translate FIC to IIC's and vice versa.
- d. Generate requirements for given quantities of IIC's.

The first two algorithms are in fact utility programs that are usually provided with the operating system and can be used on any file. On the other hand, the translation

algorithm and the algorithm for generating the material requirements are specific to this application and will be developed later on.

4. Environment

The environment for running the MRP system includes both time-sharing and batch processing. Time sharing is required for the queries whereas all other runs are in batch. ASKARS' operating system requires and permits both environments [22].

5. Information Network

Running the MRP system involves the 500 Department at NARF Alameda which is responsible for the application and some external activities that provide inputs to the system or use the system's output. Among those are NSC Oakland, the production and supply departments at the NARF, the ASKARS system and ASO. Figure 11 depicts the information network for the proposed MRP system.

C. MATERIAL REQUIREMENTS ALGORITHM

The algorithm for determining material requirements for repair of end-items is the heart of the system and therefore it will be described in full.

The algorithm is expected to be called in two cases:-

1. Queries.
2. Generation of the quarterly material requirements forecast.

The two instances differ in that a query will usually involve a single (or a small number of) end items whereas

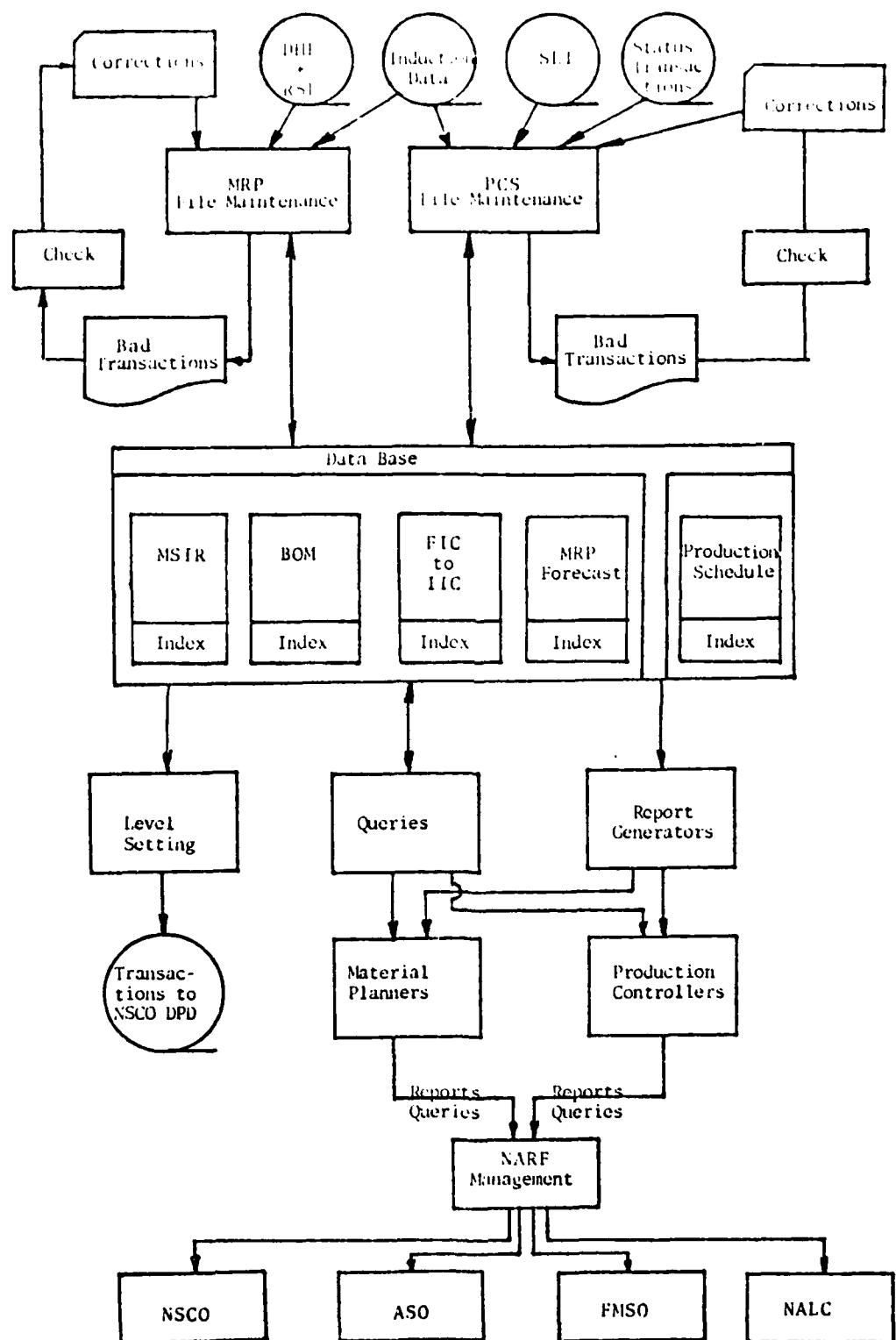


Figure 11: Proposed MRP System -- Information Network. (Frequency of runs and volumes of transactions are given in Appendix B.)

the second case involves the whole production schedule. This implies that the algorithm should provide a means for calling it for more than one end-item.

Another requirement is to allow the user (especially in queries) to provide either a FIC or an IIC and have the program do all additional work to get the end result.

A calling sequence that will meet the requirements is
CALL MRP(ID,T,Q,S,E) where:-

ID = End-item identification code (input parameter).

T = Type of identification code (input parameter).

- a. "1" for IIC.
- b. "2" for FIC.

Q = End-item scheduled quantity (input parameter).

S = Sequence code (input parameter).

- a. "1" to specify first call.
- b. "2" to specify that the subroutine was called previously in this computation.
- c. "3" to specify that there are no more end-items.

E = Error code (output parameter).

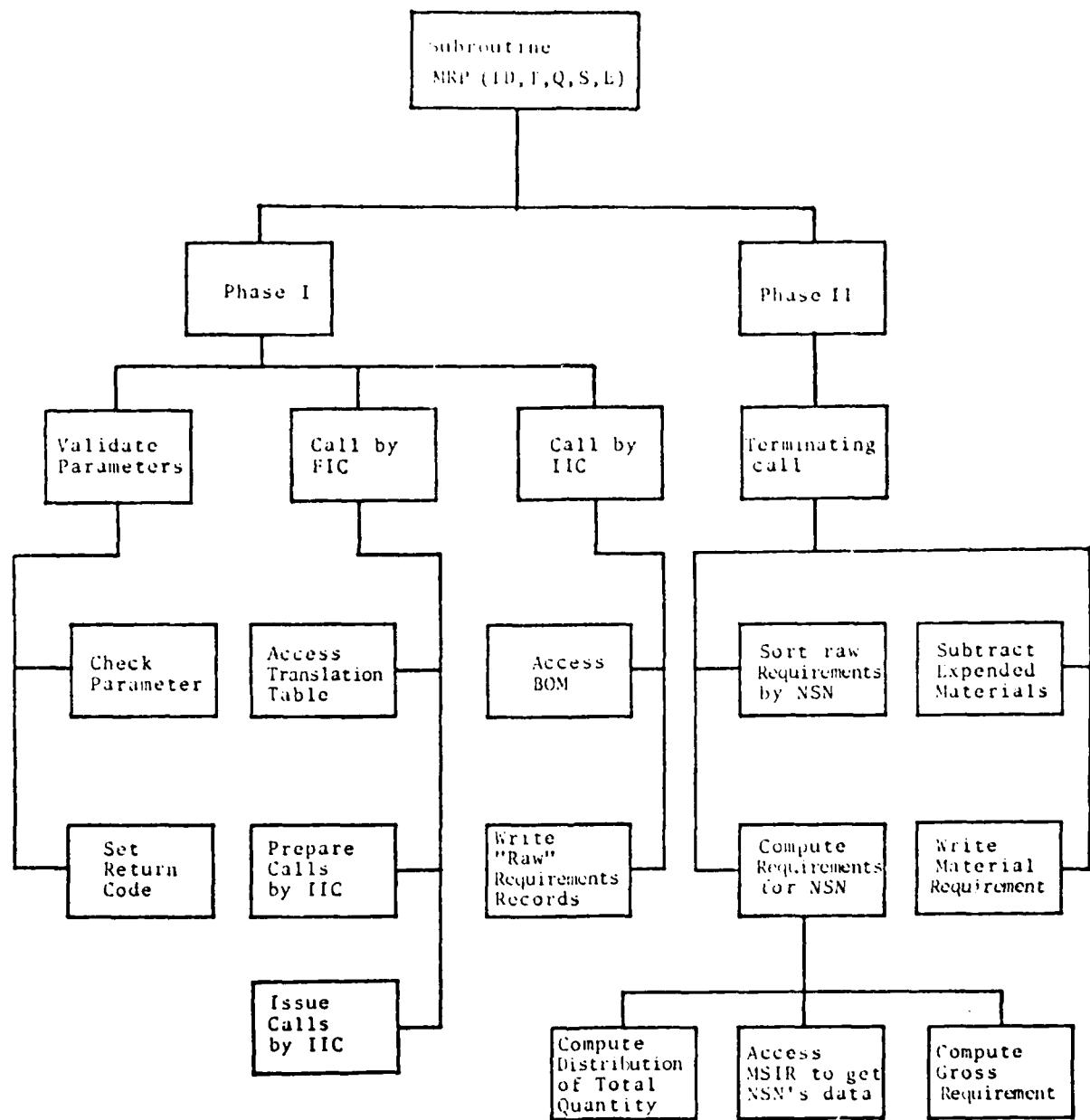
Subroutine MRP will be called from other programs. The parameters will be either supplied explicitly by the user (ID,T,Q) or implied (S) by events (first item, EOF or special ID). Of special importance is the sequence code that determines what modules will be executed. This code is set to "1" by the calling program for the first end-item. Subsequent calls will have the sequence code "2" and when there are no more items the calling program will issue a terminating

call (CALL MRP(9999,1,0,3,0)) that will tell the algorithm to proceed to the next phase of summing up requirements.

The MRP algorithm includes two phases of processing as shown in the block diagram in Figure 12. In the first phase the end-items are specified by the caller and used as access keys to the BOM (directly when end-item is an IIC or indirectly via the FIC to IIC translation table when the ID is for a FIC. Then, the BOM information and Q are utilized to compute "raw" material requirements and to write records (one per NSN) to the raw materials file (an intermediate file). This phase ends when the subroutine accepts the terminating call (S = 3). This causes execution of Phase II which begins with sorting of the raw requirements by NSN, computing total requirements per consumable, and writing the result to the final output.

Customer orders that are in the production schedule and have been started previously require special processing during RSS level setting. It is not of concern in queries since the material planner only wants to know the material requirements for a new job.

Semi-finished jobs are processed by the Regenerative MRP model. The requirements for the rest of an unfinished job are determined by subtracting the actual consumption thus far on such a job from the material requirements for the whole job. The production schedule that is the input for RSS level setting will include uncompleted customer orders. However, the actual consumption on the customer order from



Note: Control flows from top to bottom and from left to right.

Figure 12: MRP Subroutine Block Diagram.

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A PROPOSED MATERIAL REQUIREMENTS PLANNING SYSTEM...ETC. (U)
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the previous quarter will be extracted from the DHF and RSF (by customer order) and this temporary file (Expended Materials file) will be another input to Phase II of the subroutine. This means that the Raw Material Requirements file and the Expended Materials file will be read in parallel (matching) and the gross requirements for a consumable NSN will be derived by taking the difference between the total forecast quantity for that item (computed by the PRM-MRP computation) from the Raw Material Requirements file and the total quantity for that item in the Expended Materials file. Figure 13 shows the record layout for the Raw Material Requirements file. This file also contains the necessary information for computing the probability distribution function for the total requirement.

The final output from the MRP subroutine will be later formatted in the calling program (or by a different program) to either write the level setting transactions or to display them on the terminal.

Subroutine MRP involves some error checking and parameter validations. A list of the errors the program will look for is given in Table II. The successful completion or the detection of an error will be reflected in the E parameter of the subroutine which, in fact, is a return code. A return code which is other than "0" will cause the calling program to display an appropriate error message and, in the case of material forecast generation for RSS level setting, the exclusion of that end-item from the forecast.

TABLE II
Errors Returned by Subroutine MRP

Error Return Code*	Corresponding Parameter	Explanation
00	--	Successful call
11	ID	IIC/FIC does not exist
21	T	Invalid type (other than 1 or 2)
31	Q	Invalid quantity (must be an integer)
41	S	Invalid sequence code (other than 1, 2 or 3)
42	S	First call before a previous computation was completed
43	S	S = 2 without a previous call with S = 1
44	S	S = 3 and other parameters not as required
49	S	Warning. S = 3 without S = 1 or S = 2.

* The return call is an output parameter and is checked by the calling program.

NSN	Installed Quantity	Replacement Factor (P)	Induction Quantity (Q)
1	13	14	17 18 20 22 25

Figure 13: Raw Material Requirement Record Layout.

Figure 14 shows the detailed flow-chart of the subroutine.

The subroutine will require approximately 150 lines of high-level-language code. When executed, it requires on-line storage for the BOM file, the Inventory Status file (MSIR Extract), the FIC to IIC translation table, and the Raw Material Requirements file. In addition, memory is required for input and output buffers and for the table created by the subroutine for issuing calls by IIC when the original call is by FIC. These resource requirements add up to approximately 50K Bytes of memory and 100MB of on-line storage.

D. THE PRODUCTION CONTROL SUBSYSTEM

The existence of a production schedule is one of the MRP prerequisites. Since the present production and control system at NARF Alameda does not provide satisfactory and up to date information, there is a need to develop the appropriate software and maintain the required data base that will satisfy the proposed MRP application.

The Production Control Subsystem (PCS) is designed to produce the following outputs:

1. Production schedule listings.

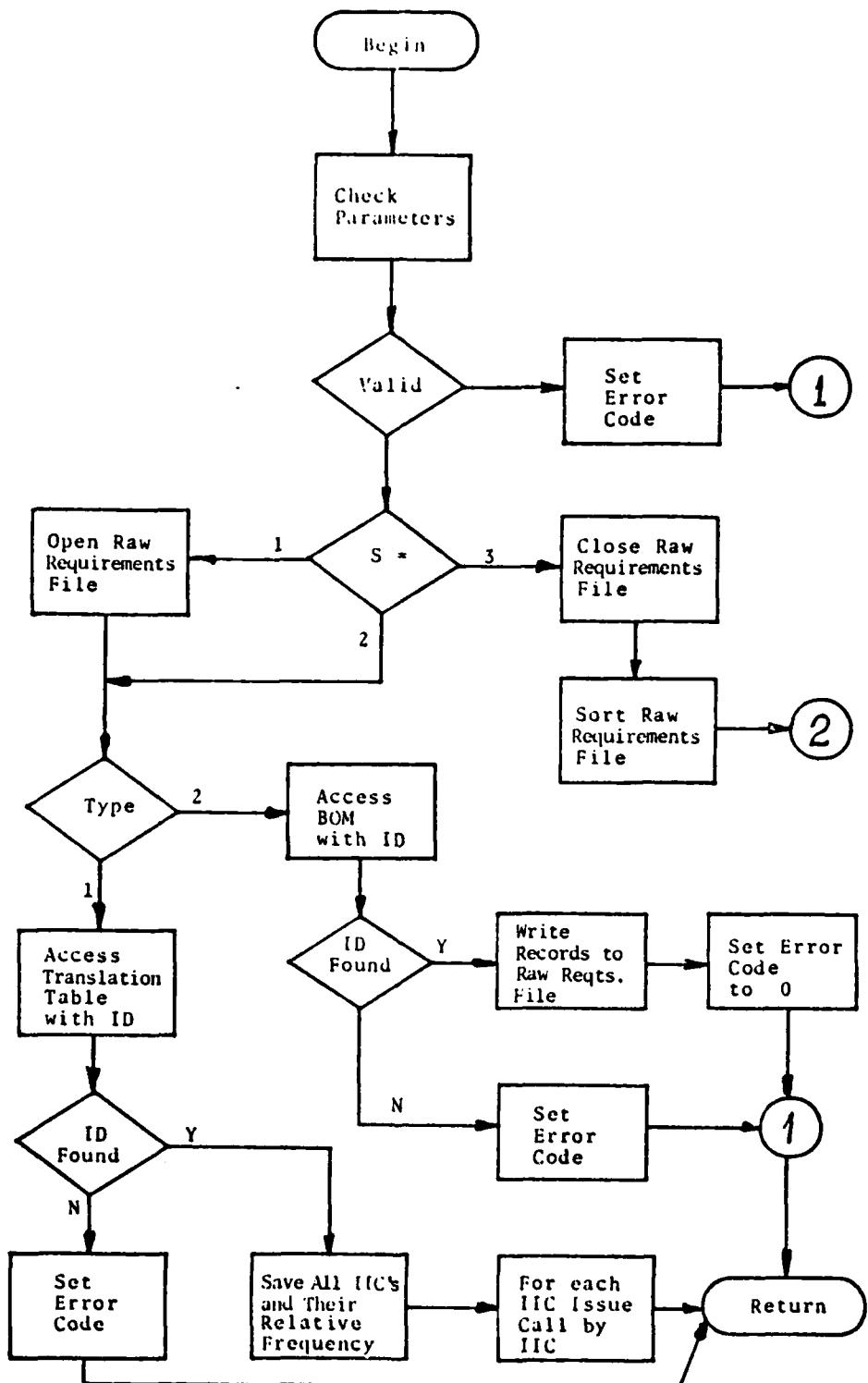


Figure 14: Flow Chart of the MRP Algorithm

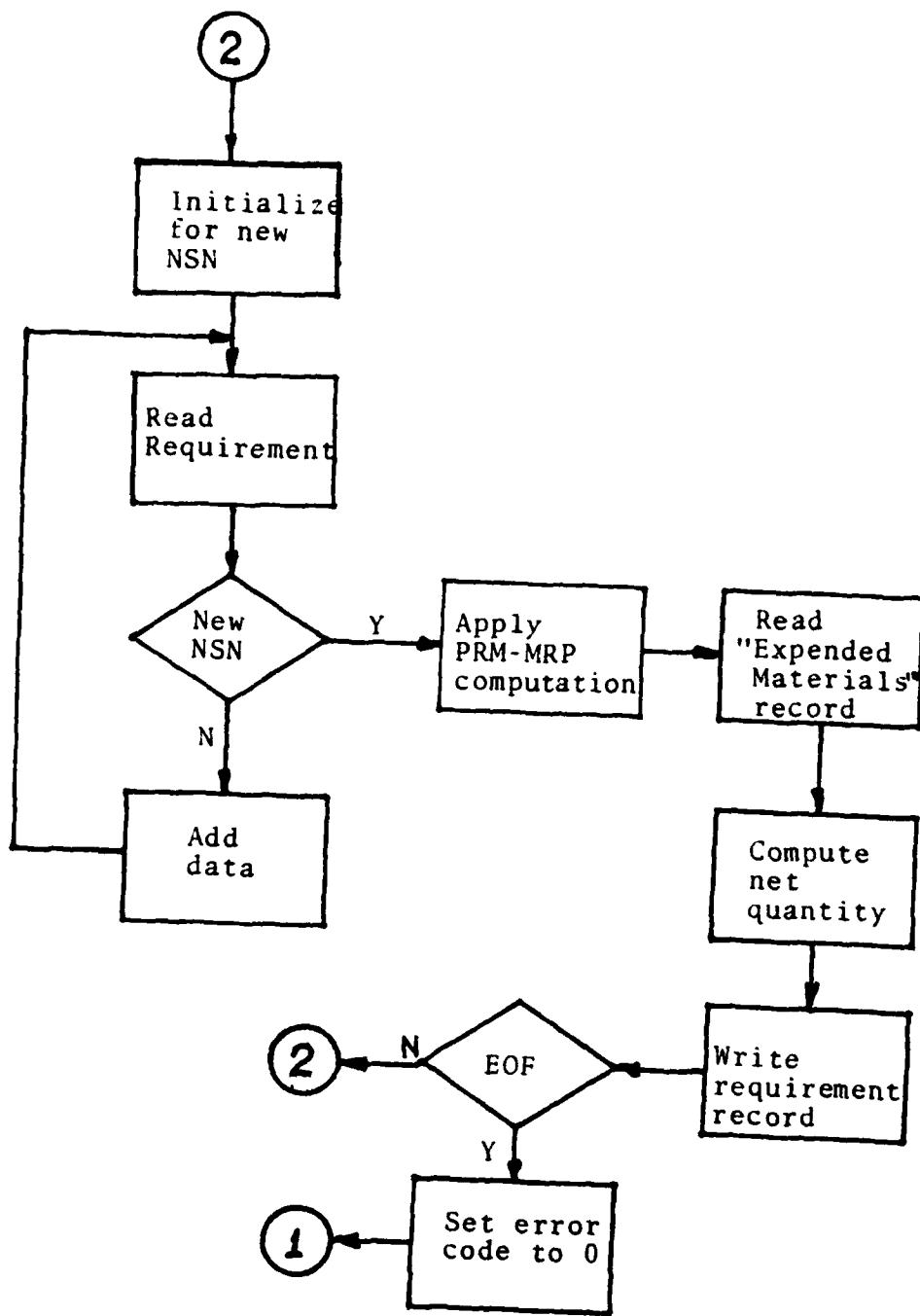


Figure 14: (continued)

2. Answers to queries about the status of customer orders.
3. Input edit reports.
4. Progress and exception reports.

Production schedule listings will be produced in two different sequences. The first sequence will list all customer orders that exist in the data-base. This report will be used by the production planners in the 500 Department and the production department head (900 Department). The report in the other sequence will be used by branch heads in the 900 Department and each report will contain only the customer orders with which the shop is involved. Both reports will contain the same information but in different sequences of customer orders.

The queries will provide essentially the same information as the production schedule listings. However, the query will refer to one customer order only and will display the relevant up to date information. The queries will be by customer order, by FIC or by IIC.

The intent of the input edit report is to give the status of the transactions that were submitted to the system. Transactions that contain errors will show up in the report with appropriate error codes specifying what the error was; for example, invalid record type, invalid dates or missing data items.

The progress and exception reports will resemble the production schedule listings in format. The difference will

be in the information printed in the reports. This information includes standard hours for completion of the whole job, number of hours expended in the job since the previous edition, and exception messages for those customer orders in which progress was not satisfactory.

Two generations of the Production Schedule file will be used to produce such reports. They will be one month (or two weeks) apart according to the frequency of printing of a report. The progress in a job will be computed by subtracting total expended hours recorded in the previous generation of the file from hours expended in the same job until the present time. This progress will be analyzed to determine if it is satisfactory. The criteria for classifying a customer order as an exception will have to be set up by the production control people. Some possible criteria are listed below:

1. Expended hours exceed standard hours by more than 20 percent.
2. The proportion of expended hours relative to standard hours is less than 70 percent of the proportion of time that elapsed relative to the total duration required for completion of the job.
3. More than 20 days have passed since the latest required finish date and the job has not been finished yet (or not reported as finished).

This report will also be produced in two different sequences: a listing of all exceptional job orders and another listing by shops/job orders.

The inputs to the system will come from two sources: transactions reported by the production control department

and inputs that were generated by other applications. Among the last group are inputs about standard hours from the Master Data Record (MDR) file, expended labor hours from the Sorted Labor Transaction (SLT) file and induction data from the Sorted WIP (work in process) History Activity file [23]. The transactions that will be written especially for the system are intended to maintain information about planned induction quantities and scheduled dates of the different job orders. They will also allow changes in the status of job orders. The transactions will allow reporting on individual job orders or on a whole FIC. This last option is especially needed for reporting a new production schedule. A simple data entry program can simplify the process of reporting the transactions mentioned above. Figure 15 depicts the layouts of the different inputs that the system will process. The MDR data will be extracted directly by the PCS file maintenance module and therefore the standard hour information will not show up in these layouts. The different transactions will be edited by an input edit program that will check the different fields for validity. Other fields, like the job order and transaction code, will be examined later by the file maintenance program to make sure that when the code specifies an update, the job order already exists.

To perform its functions, the system will maintain a PCS file that will store the information about the various job orders. The file will be a direct access-variable-length

FIC Transaction								
Trans. Type "1"	FIC	FY	Qtr	Program	Quantity	Scheduled Start	Period End	Contracting \$
1	2	5	6	7	8	9	11	12

IIC Transaction								
Trans. Type "3"	Job Order	Quantity	Scheduled Start	Period End	Committed \$	Status	Filler	Date
1	2	8	9	11	12	15	16	20

Induction Data Transaction

Induction Data Transaction								
Trans. Type "5"	Job Order	Quantity	Filler	Date				
1	2	8	9	11	12	16	20	24

Labor Hours Transaction

Labor Hours Transaction								
Trans. Type "7"	Job Order	Shop	Expended Hours	Date				
1	2	8	9	13	14	17	18	22

Transaction Codes: "1" - new data
"2" - update data

Sorting Key: 2-8, 1, 28; ascending order

The joborderdata(FIC Transaction) is required to compose job order numbers.

Figure 15: PCS Input Formats

record file. A logical record will consist of three basic structures:

1. A header for each FIC/FY/Quarter.
2. Job order trailers for jobs belonging to the above FIC/FY/Quarter.
3. Shop trailers for shops participating in the above job order.

Each such record will store the information about a particular FIC which is scheduled for a specific quarter (i.e., if the file covers a period of one year, there may be 1 to 4 different records with the same FIC). The tree structure of a logical record is depicted in Figure 16. The file will be accessed by FIC/FY/Quarter. However, this index and the translation subroutines from FIC to IIC and vice versa and from job order to IIC will allow direct access to the file by either job order or IIC, fiscal year and quarter. Figure 17 depicts the layout of each one of the PCS record components.

The header information contains information about a FIC that is scheduled. Each job order trailer represents one of the specific job orders in which an IIC belonging to the FIC will be overhauled. The job order trailer contains summary data about the job order and allows access to its shop trailers which contain information (namely standard and expended hours) about each shop that participates in the job.

The status of a FIC or a job order represents the situation of a group or a specific job respectively. The status can be one of the following:

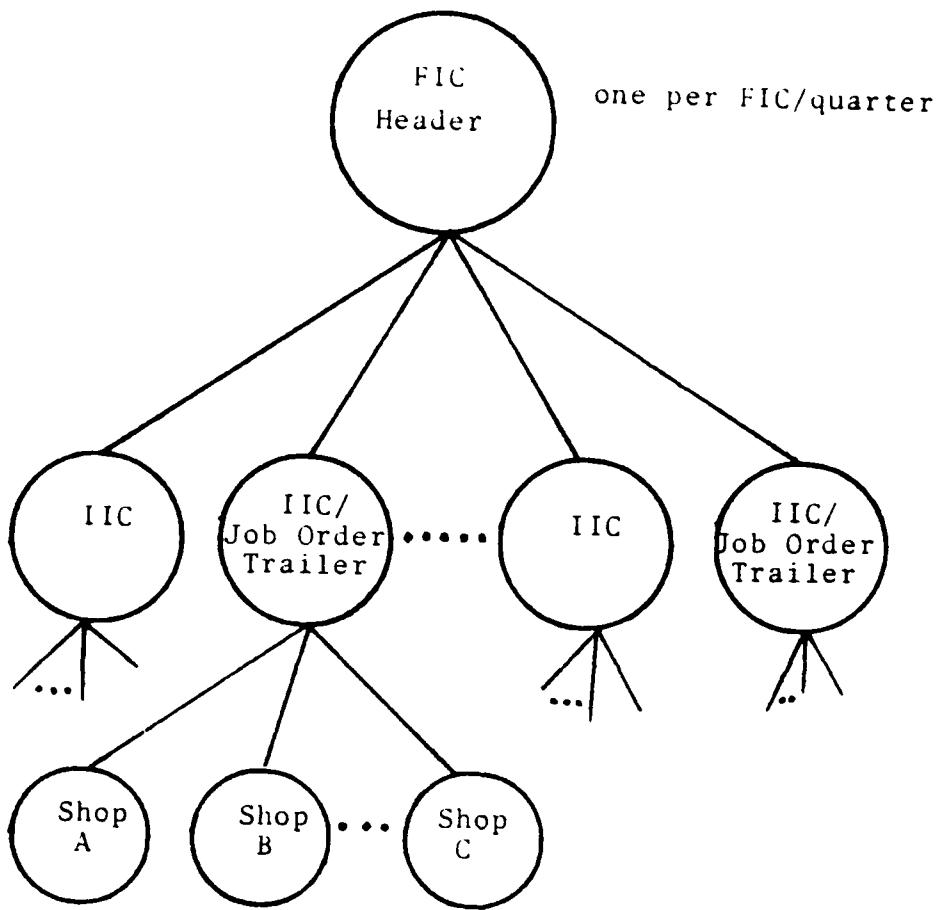


Figure 16: PCS data structure.

FIC	FY	Qtr	Program	Scheduled Quantity	Inducted Quantity	Scheduled Period	Actual Period	\$ Contracting Out	Date Created	Status	Date of Status	# of IIC's
1	4	5	6	7	8	10	11	13	14	17	18	21
						Start	End	Start	End	Start	End	Start
one per FIC/quarter												

one per FIC/quarter

Job Order Trailer

Job Order	NSN of IIC	Predicted Quantity	Inducted Quantity	\$ Committed for Contracting Out	Total Expended Hours	Status	Date of Status	# of Shop Trailers
1	7	8	20	21	23	24	26	27
						Start	End	Start

Shop Trailer

Shop	Standard Hours	Expended Hours	Actual Period
1	5	6	9

Notes: (1) All dates are Julian dates.

- (2) IIC predicted quantity is derived from FIC scheduled quantity.
- (3) Total expended hours represent the total from the IIC's shop trailers.
- (4) Actual periods are determined from labor hour transactions.
- (5) Average number of job order trailers per record = 2; Maximum = 40.
- (6) Average number of shop trailers per job order = 60; Maximum = 160.
- (7) Maximum record length = $44 + 42 \times 40 + 21 \times 160 = 5084$ Bytes.

Figure 17: PCS record layout

blank - The job has not been started yet.

"W" - The job is in process (i.e., expended hours are positive).

"C" - The job has been cancelled.

"F" - The job has been finished.

Since the FIC header represents a set of job orders, its status will reflect the status of its composite set of job orders.

The header status will be changed to "W" when the first job has been started. Similarly, it will be "F" only after the last job has been finished. The status can be changed to "C" only by a status reporting transaction (see Figure 15). Consequently, the "date of status" field will represent the date of the last change in status.

The production control subsystem software will include the following modules:

1. Input Edit

This module will validate individual data fields and will print out records that contain erroneous data.

2. File Maintenance

This involves performing further validity checks on good records from the previous step and subsequently updating of the PCS file. The FIC transactions will be the first to update the file. These transactions will cause the creation of new FIC headers, and then job order trailers with predicted quantities (based on relative frequencies of IIC's) and shop trailers with standard hours from the MDR. Subsequently, other transactions will update or add information to that which was generated by the FIC transaction.

3. Queries.

4. Report Generators.

Production schedule listings and exception reports.

Figure 18 describes the information network and the data flow. It also shows how the induction data for updating the BOM file is extracted from the PCS file.

One advantage introduced by the proposed PCS is the continuity of the production schedule, i.e., a job order stays alive until it is finished or cancelled. In this way, customer orders that were not completed in the scheduled quarter are carried over to subsequent quarters until they are completed. This saves the work of reevaluating the requirements for end-items when preparing each quarter's production schedule.

The production control system described above can be run on the 500 Department ADP system that is used to run the temporary MRP system. Weekly runs appear to be more than adequate at this time. On-line updates may be required in the future, however.

It is recommended that implementation begin with only transaction updating, even though such information may exist in a mechanized form in another part of the system. While this may result in extra manual work, it has the advantage of simplifying and increasing the involvement of the production control people in the system evolution.

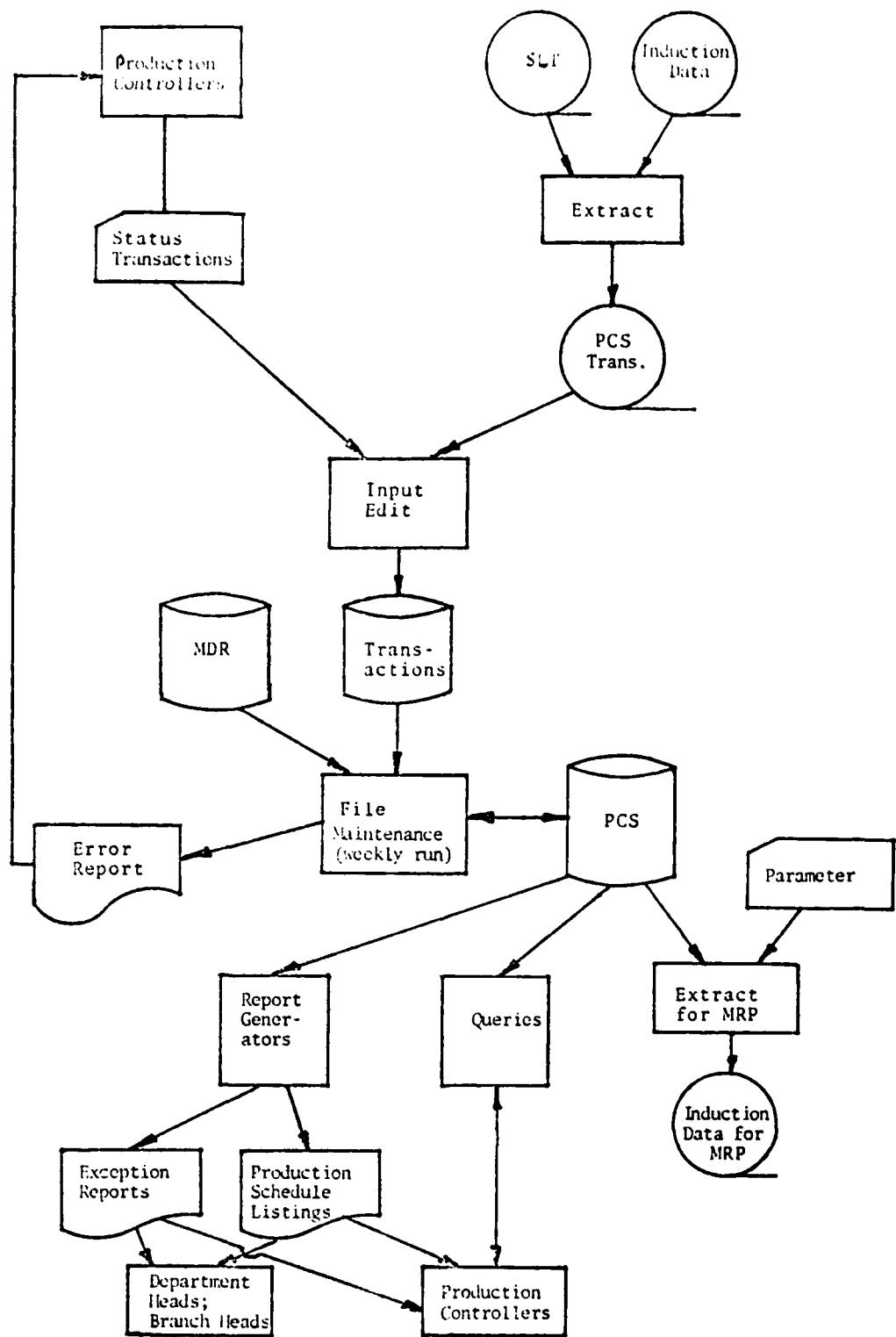


Figure 18: The Production Control Subsystem (PCS).

E. DATA-BASE DESIGN

The additional data files that are required for the MRP application are designed below.

1. The BOM File

Carrying out a production schedule requires personnel, facilities and money (for contracting out repair of special components) as well as materials. The basic MRP technique computes only material requirements. However, it will be desirable to incorporate in the same file the information about all required resources and thereby provide a tool for comprehensive production planning.

When considering all resources (except facilities), the information about each end-item should contain the following:

1. End-item information--including money for contracting out.
2. Consumable materials information.
3. Labor hours information.

This implies that the records for each IIC should have a tree structure with a root, being a header containing the end-item information and two branches, one for materials and the other for labor hours. Each branch would be a set of fixed length records representing either a material or a shop's labor hours. Figure 19 depicts the structure of an IIC's logical record.

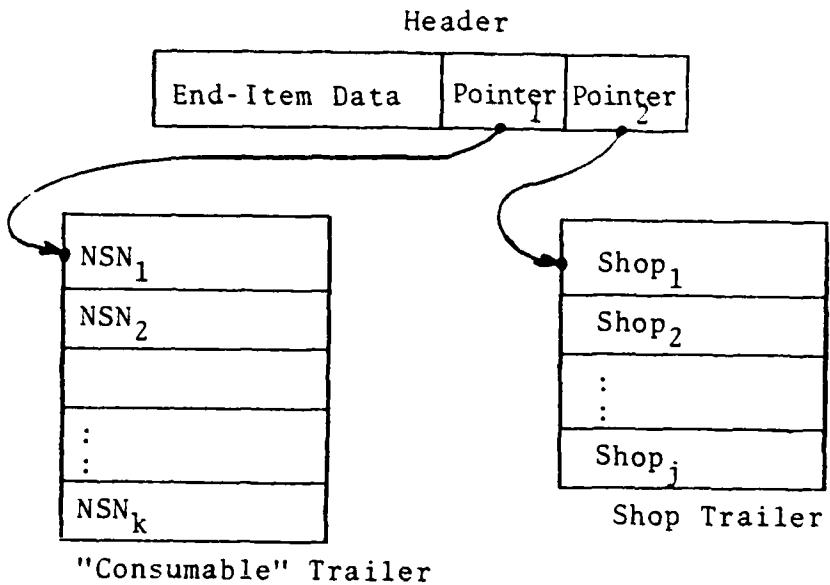


Figure 19: BOM Data Structure

As shown in Figure 19, for each IIC there will be one header, one consumable trailer per consumable item and one shop trailer per participating shop. The information in the header will allow access to the trailers by either having there a pointer or the number of different trailers. Figure 20 depicts the layout details of the header and trailers.

An important factor in designing the BOM is the fact that the NARF is involved in maintenance rather than production. The implication of that fact is that instead of having a BOM that experiences only addition of new IIC's, as in the case of manufacturing, the file will require changes to existing data, namely the replacement factors. Also, there must be a distinction between estimated replacement factors (representing new or modified items) and items that have

IIC Header									
IIC	NSN of IIC	COG	U/I	U/P	Expected Materials	Expected Labor Hours	Contracting Out \$	Date Created (MM/YY)	Date of Last Update (MM/YY)
1 4	5 17	18 19	20 21	22 25	26 29	30 33	34 37	38 41	42 45
Consumable Item Trailer									
NSN	COG	U/I	U/P	Installed Quantity	Estimated Replacement Factor (P)	Estimator Code	Date of Last Estimate (MM/YY)	Total Induction Quantity	Actual Replacement Factor
1 13	14 15	16 17	18 21	22 24	25 26	27 28	29 32	33 35	36 37
Shop Trailer									
Shop	Average Labor Hours	Variance Std. Hours	Date of Last Update (MM/YY)	# of Updates					
1 5	6 9	10 13	14 17	18 20					

Notes:

- (1) Average number of consumable item trailers = 50; maximum = 1200. Consumable trailers will be read in groups that don't exceed 150 trailers.
- (2) Average number of shop trailers = 12; maximum 160.
- (3) Maximum record length = $47 + 1200 \times 37 + 160 \times 20 = 47,647$ Bytes.
- (4) Maximum buffer = $47 + 150 \times 37 + 160 \times 20 = 8797$ Bytes.

Figure 20: BOM Record Layout

already been overhauled. The process of maintaining the replacement factor data is described in Appendix D.

The file will be an index-sequential file with the IIC being the access key. When only the FIC is known, access is possible by using the FIC to IIC translation table. Appropriate read/write functions will make it simple for application programs to access the file.

The implementation of the shops branch in the BOM is independent of the other parts. Since the integration of the inventory and production control applications at NARF Alameda is not going to take place in the near future, it is recommended that the implementation of this part be postponed until the materials segment works properly and the organization is ready to manage the rest. Deletion of the shop data can simply be achieved by reporting only materials data to the system. This will create IIC records with no shop trailers. Because the shops branch will not be implemented with the rest of the system, this part will not be included in the file maintenance design.

2. FIC to IIC Translation Table

The intent of this file is to provide the data for translating a FIC end-item identification into the specific IIC's that comprise it. The file also allows the opposite translation from IIC to FIC. Finally, the file provides the relative frequency with which the specific IIC's are expected to be inducted. This last element is vital for the translation of a production schedule by FIC into an IIC schedule.

The file will be composed of fixed length records, one record per IIC. The organization of the file will be such that all records for one FIC will be organized sequentially. Therefore, to find the composition of a FIC, one has to access the file and read it sequentially until the record contains a different FIC. Figure 21 depicts the organization and record layout of the file.

FIC ₁	IIC ₁				
	IIC ₂				
	IIC ₃				
	IIC ₄				
FIC ₂	IIC ₅				
	IIC ₆				
FIC ₃	IIC ₇				
⋮	⋮				
FIC	IIC	Total FIC Quantity	Total IIC Quantity	Relative IIC Frequency	NSN of IIC
1-4	5-8	9 - 14	15 - 20	21 - 22	23 - 35

Figure 21: FIC to IIC translation file record layout.

3. Other Files

A file that has not been designed yet is the inventory status file. This file should contain information about all NSN's involved in the requirements forecasting process. The easiest way to get that data will be to get an extract from NSCO's MSIR which will contain all records related to items stored in the RSS. Using that file will save its maintenance by the NARF. Since the information about the quantities is not used by the MRP application, it will be sufficient to have a new copy of the file each week or two. Figure 22 depicts a layout of this file that will satisfy the proposed application. Any similar structure that is readily available is also satisfactory.

NSN	COG	U/I	U/P	Nomenclature	RSS Qty On Hand	RSS Qty On Order	Date of Last Trans. (Julian)	Wholesale Qty on Hand
1 13	14 15	16 17	18 27	28	41	42	45 46 49 50 53	54 57

Note: Any other structure that contains these fields is acceptable.

Figure 22: MSIR Extract Record Layout.

Another file that will change with the implementation of the proposed system is the MRP forecast file. The information that was added to the file for current production control needs will no longer be required. However, some method will still be needed for computing the distribution

of the gross requirements. Thus, the appropriate new structure is shown in Figure 23.

FIC	IIC	NSN of FIC	NSN of IIC	U/I	U/P	NSN of Consumable	COG of Consumable	Installed Quantity per IIC
1 4	5 8	9 21	22 34	35 36	37 44	45	57 58	59 60 62

IIC Scheduled Quantity	Total* Requirement Quantity	Extended Price per Consumable
63	65	66 69 70 77

* Replacement factor - total requirement/(IIC Scheduled Quantity * Installed Quantity).

Figure 23: MRP forecast record layout

F. SOFTWARE DESIGN

The software of the proposed system will consist basically of the same modules as the temporary system. The differences are in the contents and in the set of functions that will be used by the different modules. Figure 24 depicts the block diagram of the main software modules.

1. File Maintenance

This module consists of the programs to maintain the BOM file and the FIC to IIC translation table. The MSIR is not maintained but reproduced whenever needed and the Material Forecast file is generated by the requirements generation module and updated by queries.

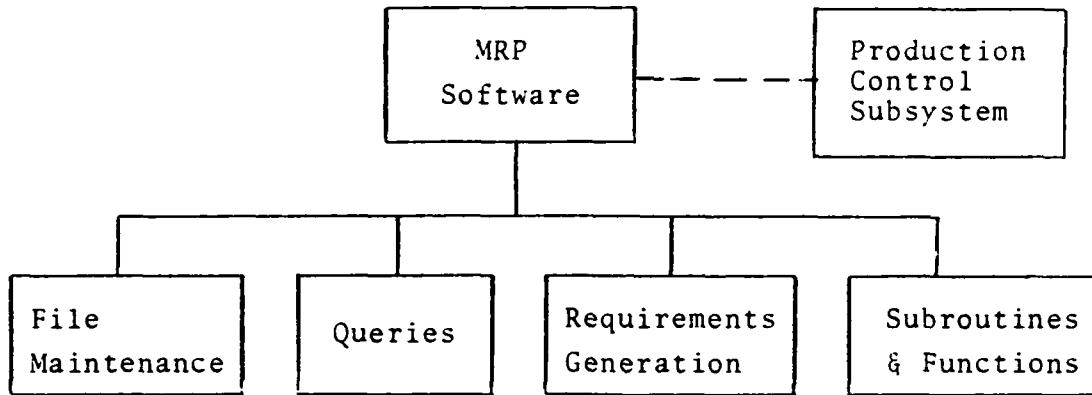


Figure 24: Software Modules

a. BOM File Maintenance

The intent of this module is to update the BOM file with respect to the composition of the end-items, the replacement factors of the components, and the labor hours and shops participating in the job.

The information that will update the BOM will come from two sources:-

1. Transactions written by the material planners. These are intended to introduce new items or to update the file after technical modifications have taken place.
2. Expended materials and labor hours. This historical data will be used to update previous data in the file.

The file maintenance process consists of three steps as depicted in Figure 25. The first step deals with collection of the various inputs (induction data, expended materials and labor hours and the transactions written by the planners) into one file. This program receives a parameter that tells the program the date of the previous BOM maintenance

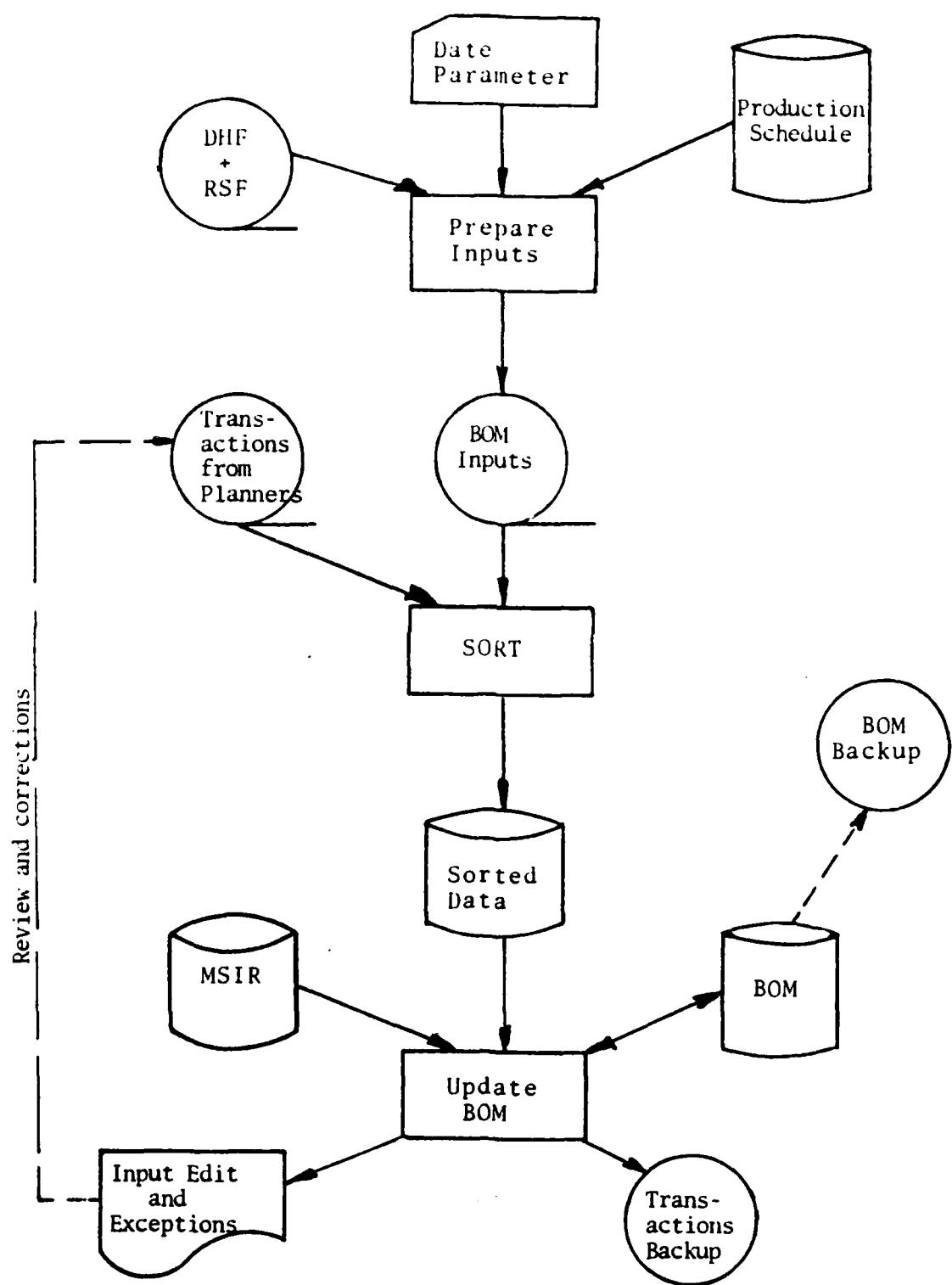


Figure 25: BOM File Maintenance Run

run and scans the production schedule file for jobs that were completed after that date. For each completed job the program writes to the output file one induction data record (type 1 record as shown in Figure 26) and a set of shop data records (type 8 records). These latter records contain expended hours by one shop on the specific job. At the same time the job number is entered into a table of completed jobs. When the end of the production schedule is reached, the table is used as a look-up table for extracting expended materials from the DHF and the RSF. For each record that belongs to a job that is in the table, the program writes a type 4 record (requisitioning data).

The second step simply sorts all inputs and prepares them for the final step in which the transactions are validated and used to update the file. The sorting is based on columns 1-22 (IIC, record type, NSN/shop, date). Ascending order will assure that the transactions with header information will be processed first, and later transactions for materials and labor hours (i.e., in the same order that the trailers are organized in the file).

Type 1 transactions are also used to create/add new IIC's to the BOM file. Type 3 and type 6 transactions provide the additional consumable items and labor hours information required to forecast requirements. Types 1, 4 and 8 transactions are used to compute actual average quantities of materials and labor hours.

IIC Data

IIC	Type "0"	NSN of IIC	Transaction Date (J)	Contracting S (I8)
1 4	5	6 18	19	22 23 30

Induction Data

IIC	Type "1"	Blank	Transaction Date (J)	Quantity (F8.2)
1 4	5	6 18	19	22 23 30

Material Estimates

IIC	Type "3"	NSN of Consumables	Transaction Date	Replacement Factor (I2)	Planner Code	Installed Quantity (I3)
1 4	5	6	18 19	22 23	24 25	26 27 29

Requisitioning Data

IIC	Type "4"	NSN of Consumables	Transaction Date	Quantity (F8.2)
1 4	5	6 18	19	22 23 30

Shop Estimates (Labor Hours)

IIC	Type "6"	Blank	Shop	Transaction Date	Hours (F8.2)	Planner Code
1 4	5	6 13	14 18	19	22 23 30	31 32

Shop Data

IIC	Type "8"	Blank	Shop	Transaction Date	Hours (F8.2)
1 4	5	6 13	14 18	19	22 23 30

Figure 26: BOM file maintenance transactions

As mentioned earlier, the transactions are sorted by IIC and by the type of header/trailer the data in the transaction is to update. Consequently, the update process treats each IIC that has transactions individually, starting with creating/updating the header, creating/updating consumable's trailers and finally creating/updating shop trailers. The process of updating an IIC begins with reading a transaction that contains an IIC different than the IIC in the previous transaction. This causes an access to the BOM in an attempt to read the IIC's old data. If the IIC existed, the transactions are considered as changes; otherwise they will create a new IIC entry in the BOM. In this case there is a requirement to have additional transactions with material/shop data.

The process of updating trailers is also designed to treat individual trailers separately (i.e., one consumable or one shop at a time). The induction data transaction is processed first and all it does is to save the induction quantity in memory. Subsequently, material estimate transactions (or shop estimates) simply update the appropriate fields in the trailer, whereas for a requisitioning (or shop data) transactions the expended quantity is computed and divided by the induction quantity to give a new average consumption. This average is exponentially smoothed (see Appendix D) with the old data and the updated information is saved in memory. In the course of processing these transactions

the program will also have to verify that all data fields contain valid data.

Another function that the program performs is to detect exceptional replacement factors. Whenever the difference between the old and the new factors is greater than 0.2 (or any other value that can be selected) the program will print the data in the input edit and exceptions report. This report will have to be checked and, if there was an error, the appropriate correction should be made.

Figure 27 describes the main functions that will be performed by the BOM file update program when treating an IIC. Although the flow chart appears to contain many details, it is intended as a summary rather than the actual flow chart of the program. It must also be remembered that the labor hours branch will be implemented at a later time so that it is too early to go into more details than are needed to describe the general process.

The complete BOM file maintenance run will be executed once per quarter. This run will take place a short time before the workload conference so that an up-to-date BOM file will be available for generating the material requirements. However, runs that just process transactions reported by the planners can be run at any time so that new data would not have to wait up to three months before being processed. Weekly runs for such purposes are probably sufficient.

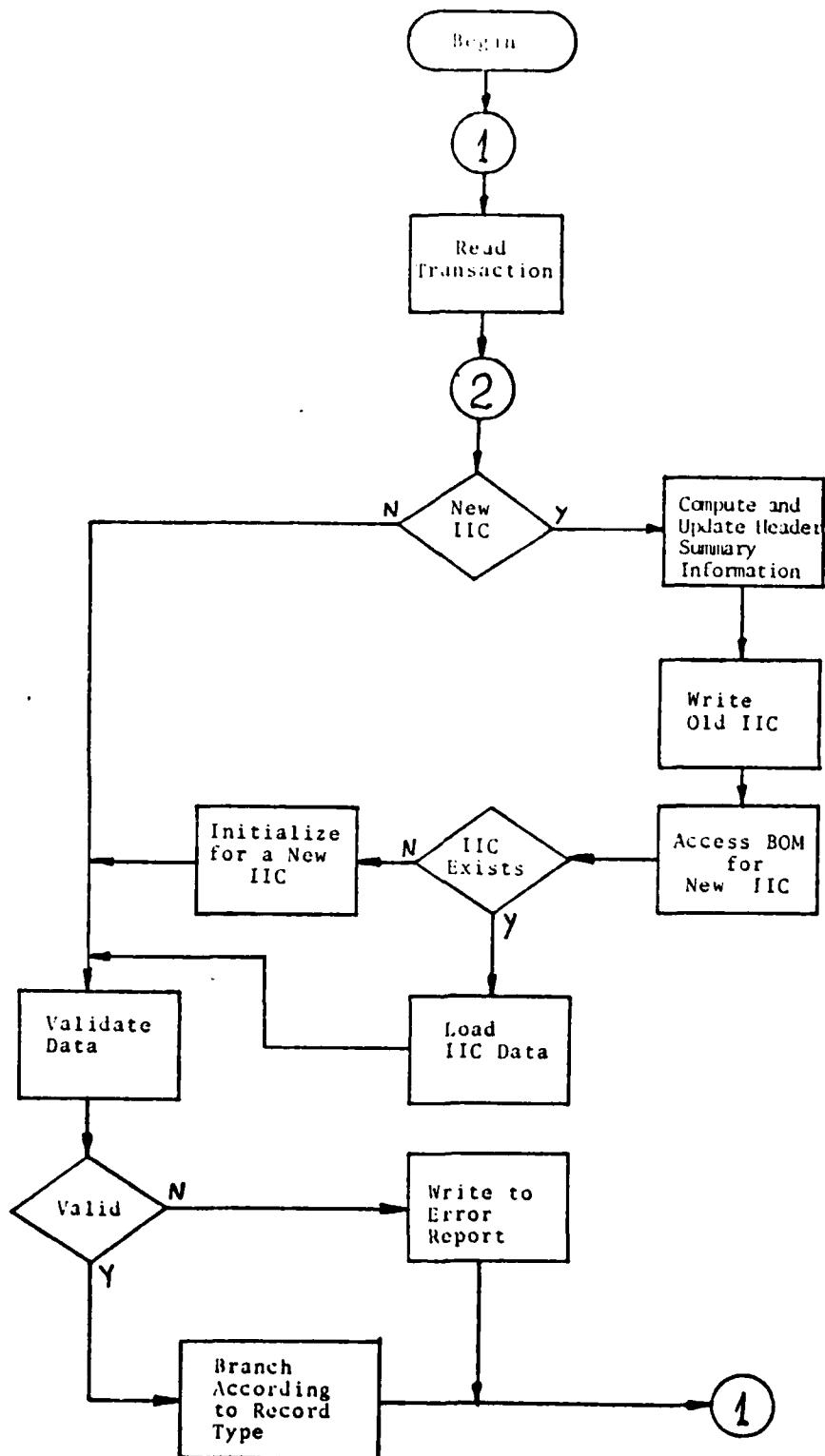


Figure 27: Updating IIC Data in the BOM File

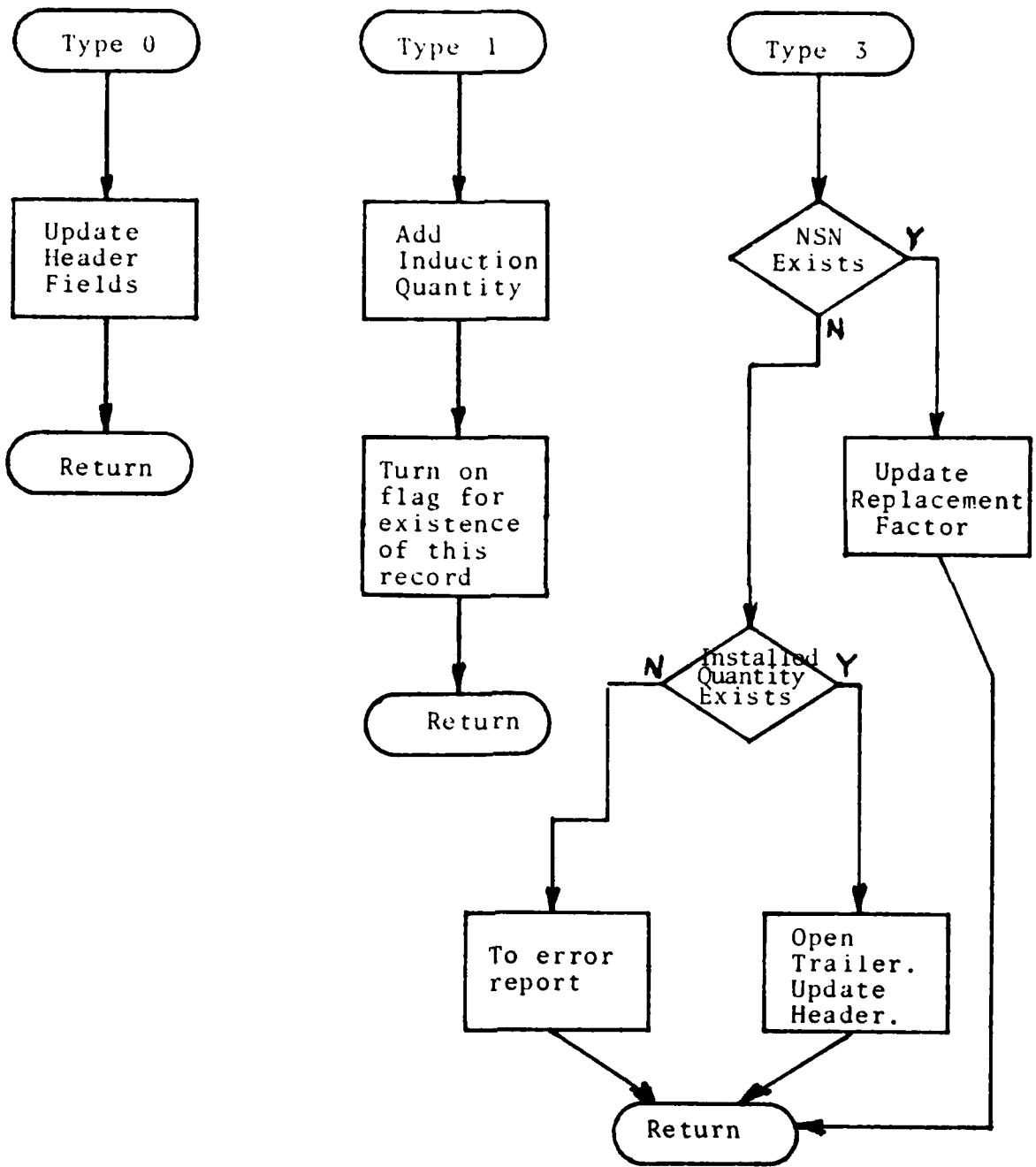


Figure 27: (continued)

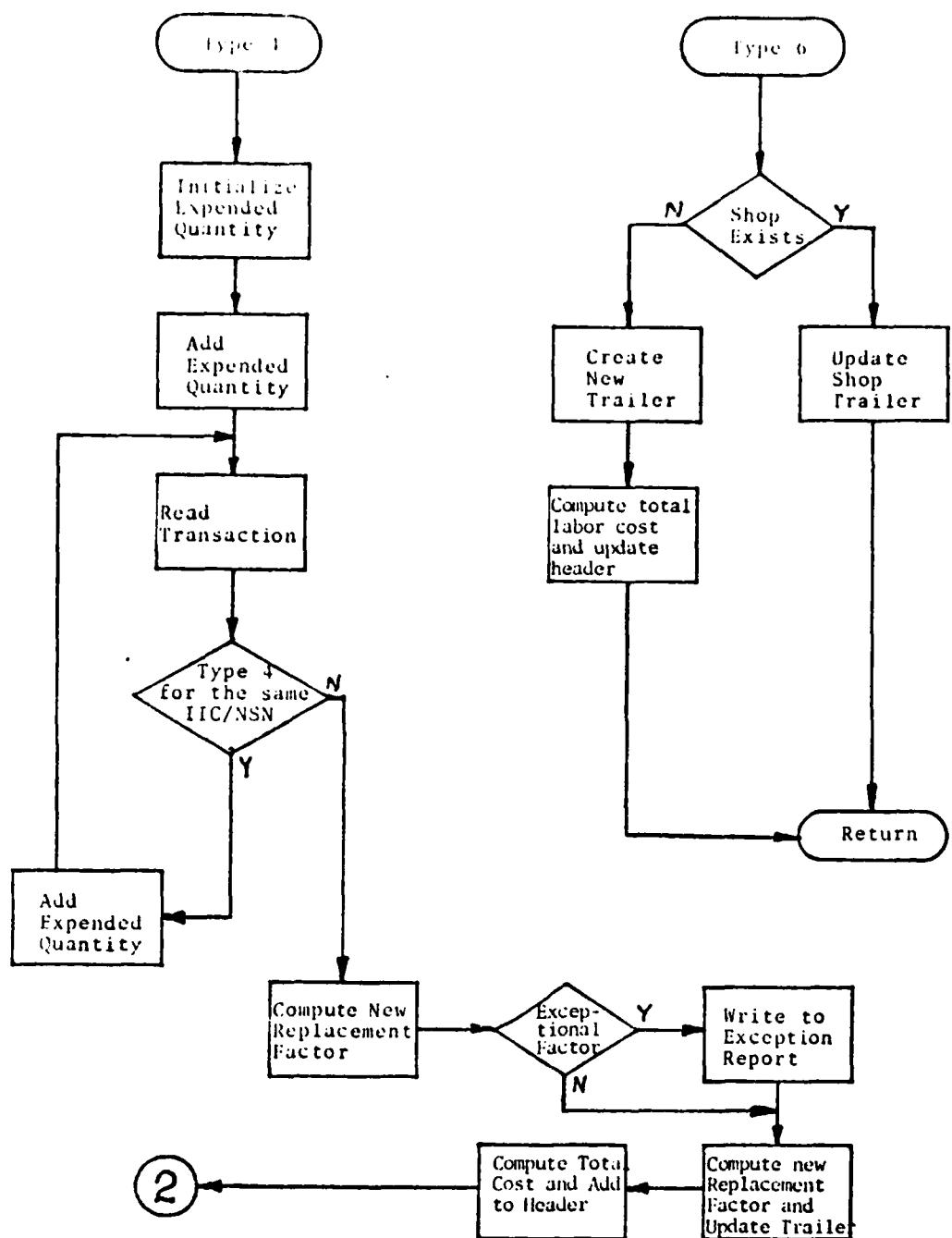


Figure 27: (continued)

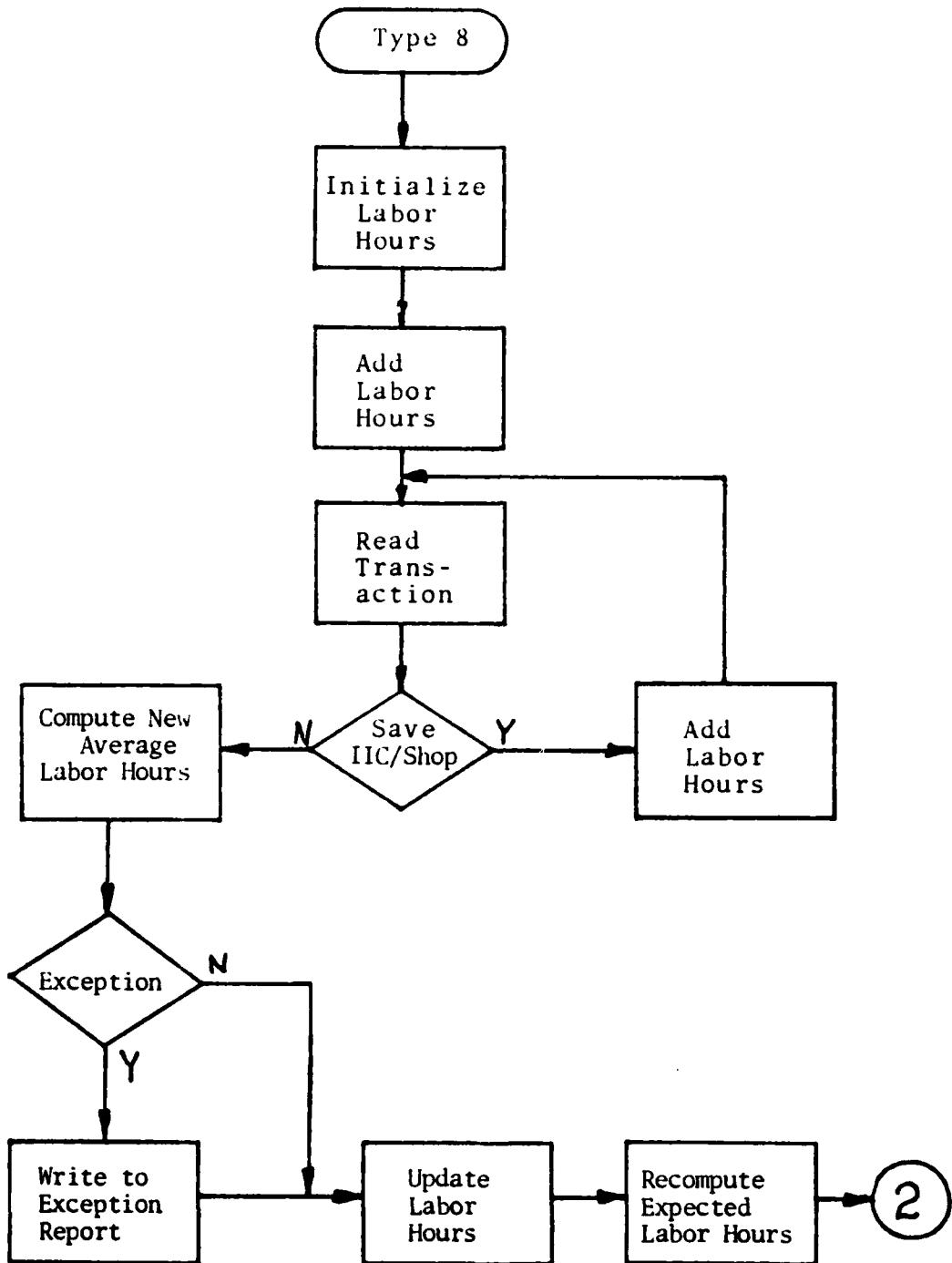


Figure 27: (continued)

b. Maintenance of the FIC to IIC Translation Table

The maintenance of this file has two goals:-

1. Update the file with new end-items.
2. Update the relative frequency of IIC's.

The information from the Quarterly Family Tape (QFT) will be used to keep track of all existing end-items. This file is maintained by ASO and is delivered to users on a quarterly basis. It contains one record per IIC and each such record contains the FIC to which that IIC belongs.

The relative frequency of IIC's will be updated by the induction data. A record will be provided for each induction, containing the IIC that was inducted, the induction quantity, and the FIC. The input will be sorted by FIC and IIC and by ascending record type ("1" for QFT records and "2" for induction data).

The principle used in updating the file is to update all information about a FIC as one unit. Therefore, for FIC's that have transactions, their records from the old file are read into an array in memory. Then the transactions update appropriate quantities or open new entries for new IIC's and at the end of the FIC, updated records are written to a new file. FIC's that have no transactions are just copied from the old to the new file.

Figure 28 depicts the maintenance run and Figure 29 is the flow chart for updating one FIC.

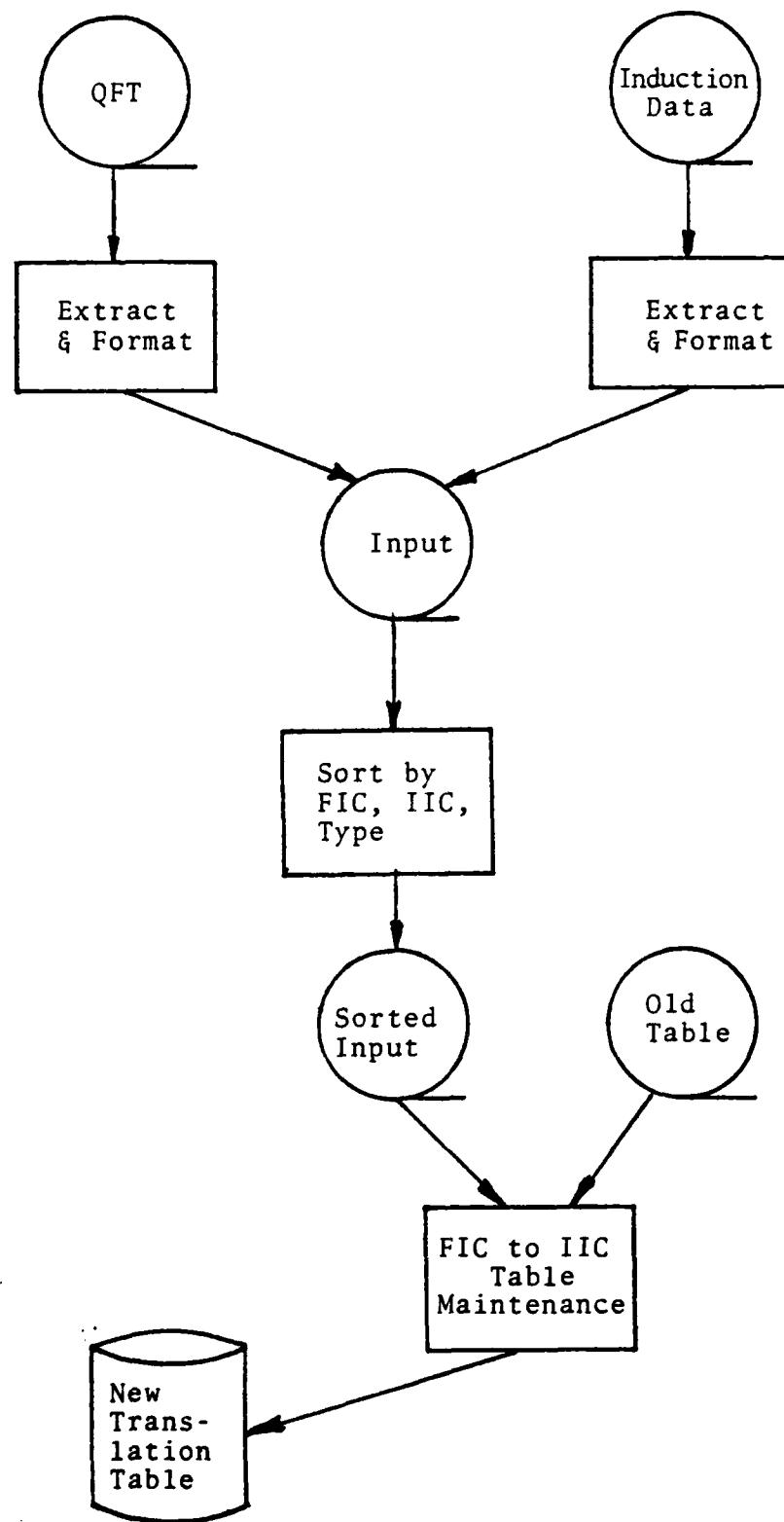


Figure 28: FIC to IIC Translation Table File Maintenance

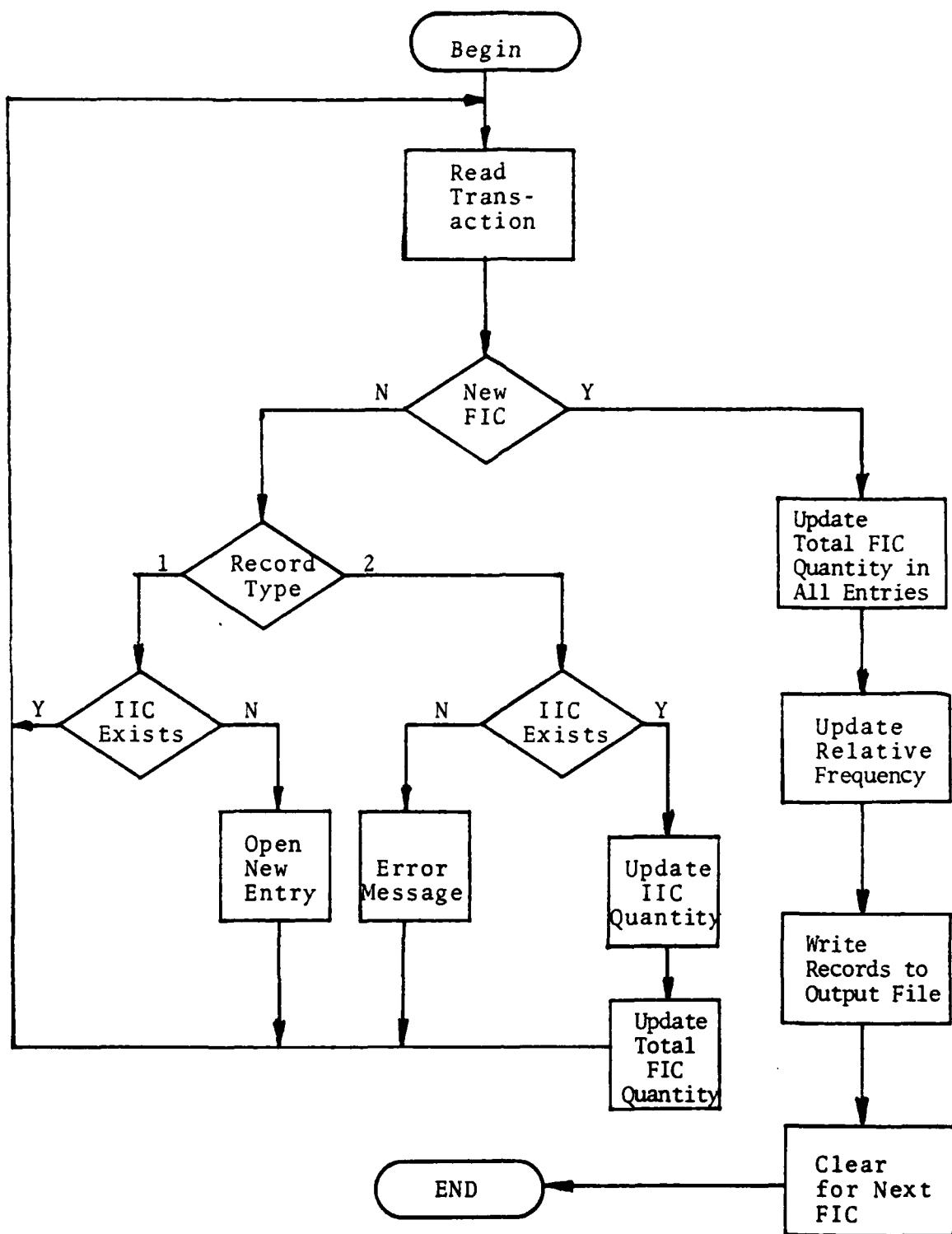


Figure 29: Updating FIC Data

2. Queries

Implementation of the proposed system will require conversion of the temporary system software to fit the new data-base. The use of the MRP subroutine will simplify significantly the query program and will usually require a simple "driver" program that will prompt the user and translate his inputs into appropriate MRP subroutine calls.

To facilitate use of the system, "query numbers" will be assigned to each type of query. They will allow the user to choose the query type dynamically. In the selection mode the system will display all alternate queries available for use and let the user specify his choice. This will then cause branching to the appropriate module that will retrieve the requested information.

Figure 30 depicts the block diagram of the query module.

3. Requirements Generation

This module will be significantly different from the one in the temporary system because the proposed requirements generation program will consider job orders that are already in process and because the use of the MRP subroutine will simplify the program.

The generation of the requirements will consist of several steps, as shown in Figure 31. The first step scans the production schedule file to extract and build a list (in memory or as a temporary file) of all job orders that will be worked on during the coming quarter. This means that an

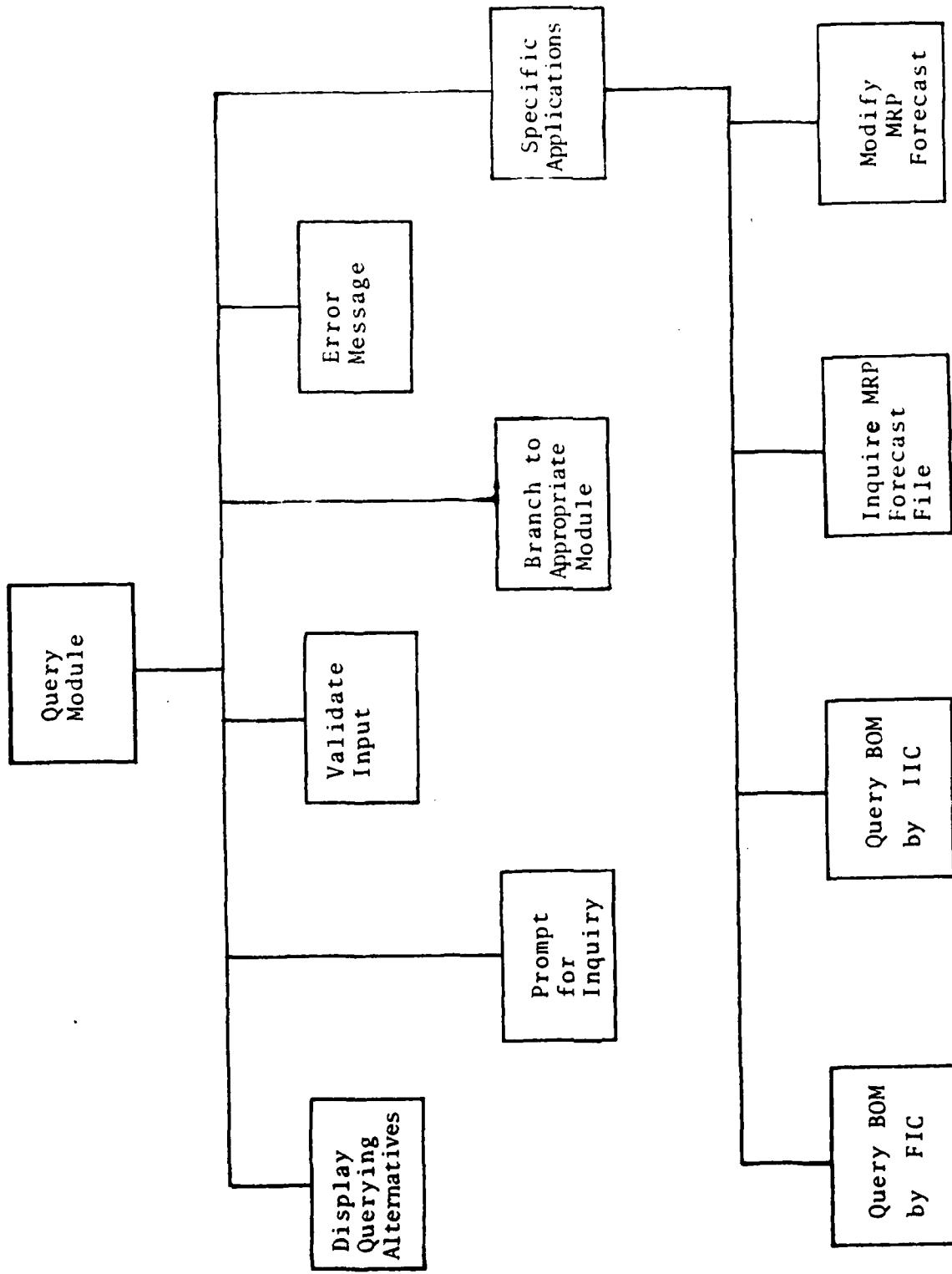


Figure 30: Query Module Block Diagram

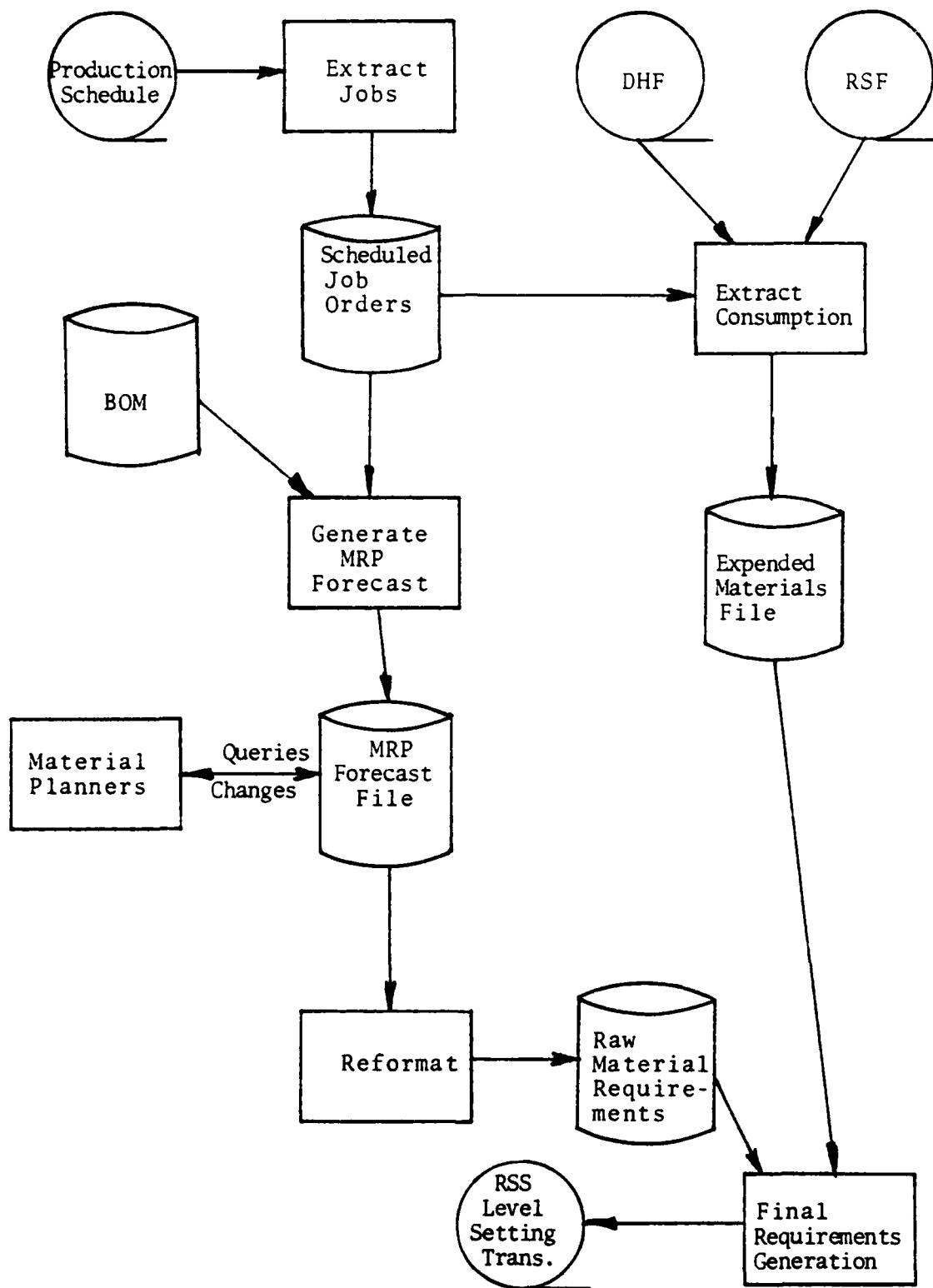


Figure 31: Material Requirements Generation Run

entry will be opened for each job order whose planned period falls in the coming quarter and whose status is blank, "W" or "P". Each such entry (or record) will contain the job order (which contains the IIC) and the scheduled quantity.

The next step will use those job orders as a table to extract from the DHF and RSF the materials that have already been expended in continuing job orders. The output of this step is the Expended Materials file.

The third step is the actual preparation of the MRP Forecast file. In this phase the program issues calls to the MRP subroutine and transforms the output from the subroutine into records with the structure of the MRP Forecast file.

After the material planners finish updating the MRP Forecast file², the computation of the requirements for each consumable item is performed. To do that, the intermediate file that subroutine MRP needs is regenerated from the final MRP forecast file and both the intermediate file and the Expected Materials file are input to the program which issues a terminating call to subroutine MRP. The subroutine then uses the proposed model to generate the final requirements forecast. This output is formatted into RSS level setting transactions (AOA transactions).

4. General Purpose Subroutines

The MRP application involves several functions that will be performed by several programs. It will be very useful

²They can modify only the "total requirement quantity" field--see Figure 23, columns 66-69.

to have those modules shared by the different programs, thereby saving programming effort and assuring consistency.

A set of such functions are the read/write functions. The application involves several variable-length-record files which may present a problem to novice programmers. The problem can be solved by a set of I/O routines. Each routine will perform either read or write. It will be called with parameters that will specify the program's need and will return (or write) a complete logical record or a required header/trailer. Some additional work can be saved by having the various data structures in software libraries. Those structures would be copied by user programs and would save the definition by each one.

Another subroutine that will be required is a subroutine that accepts the mean and variance of a random variable that has a Normal distribution, and a desired cumulative probability and provides the value that satisfies that probability. This function would not have to be written by local personnel but can be bought from software vendors. This function is required for the application of the proposed model.

Another required subroutine is one which identifies the IIC that is being overhauled in a given job order. The IIC is contained in the job orders but its position is different according to the production program the job belongs to. By maintaining a table of the positions of the IIC in various job numbers, one can easily identify an IIC from a job order.

This function will be needed to allow access to the production schedule or to the BOM file when only a job order is given.

G. SYSTEM CONFIGURATION

The intent of this section is to identify the computer resources that will be required for running the proposed MRP application. The sources that were utilized in estimating the resources are:

1. The information about the temporary MRP application.
2. Comparison of complexities of the existing and proposed software and data-base.
3. Personal experience of the author with similar systems.

This analysis takes into account an annual file size and processing growth factor of 10 percent and assumes a useful life period of ten years [26].

1. On-Line Storage

On-line storage is required for the data-base, work areas, and software libraries. The last two elements can be ignored here because of their relative small size and also because they are shared by other applications.

Table III shows estimates of the net sizes of the various files. When considering inter-record gaps of 30 bytes and allowances of 10 percent for overhead and indices, the required storage becomes $(118924 + 30 \times \frac{2306000}{1000}) \times 1.1 \approx 207 \text{ MB}$. When the future growth during the useful life of the system is included, the requirement at the end of ten years becomes

$$207 \times (1.1)^9 \approx 488 \text{ MB} \quad \text{for on-line storage.}$$

TABLE III
File Sizes

File Name	"Record" Name	# of Records	Record Length (Bytes)	Net Size (K-Bytes)
BOM	IIC header	14,000	47	658
	Consumable Trailer	700,000	37	25,900
	Shop Trailer	170,000	20	3,400
FIC to IIC Translation Table	IIC Record	14,000	35	490
MRP Forecast*	Consumable Record	1,000,000	77	77,000
MSIR Extract*	NSN Record	40,000	57	2,280
Production Schedule*	FIC Header	20,000	44	880
	Job Order Trailer	28,000	42	1,176
	Shop Trailer	340,000	21	7,140
Total		2,306,000		118,924

* Numbers of records were inflated to represent required capacity at war time.

This storage quantity is less than 30 percent of the 1200 MB disc storage that ASKARS will have as a minimum [22:3.3.8].

2. Off-Line Storage

The required off-line capacity imposes no constraint except to tape drives. Two tape drives will allow copying of files, taking back-ups, and running the programs that will usually have input (transaction) tapes.

3. Main Memory

Main memory is required for programs (and their I/O buffers) that are run simultaneously. Since file maintenance and queries would not run concurrently, main memory requirements are computed for the file maintenance module and the general purpose subroutines. As Appendix C shows, the length of those modules is $2000 + 450 = 2450$ high level language statements. Assuming an average of 10 machine instructions per statement and an average of 6 bytes per instruction, the total main memory amounts to $2450 \times 10 \times 6 = 147000$ Bytes. When adding buffers for the BOM file (≈ 8.8 KB), the production schedule file (5 KB) FIC to IIC translation table (35 bytes) and transactions (80 bytes), at least 165 KB are needed in addition to the memory resident operating system modules. However, it must be noted that systems whose operating system provides virtual memory may utilize less real memory.

4. Processing Time

When computing processing time, one has to distinguish between three different modes of operation during a quarter, each of which requires different processing capacities.

The highest capacity is required when the maintenance of the BOM file takes place (once per quarter in the third month) and when the MRP Forecast file and RSS level setting transactions are generated. A lower capacity is required for maintaining the Production Schedule file (at least once a week). The lowest, but most frequently required capacity is for the queries.

This imposes a changing load on the system and it will require timing the execution of various programs to prevent temporary peak loads.

In estimating the total processing time for MRP and PCS, the following assumptions are made:

1. 10 Machine instructions per statement.
2. Average clock pulses per instruction = 12.
3. Clock rate = 3 MHZ.
4. During file maintenance, one-half of all statements are executed for each transaction.
5. During queries, one-fourth of all statements are executed once per query.
6. In report generating type programs, each statement is executed once.

Applying assumptions 1 through 3 gives an average statement execution time of $10 \times 12 \times \frac{1}{3} = 40 \mu\text{sec}$.

When using this average execution time with the input rates from Appendix B, the program sizes from Appendix C, and the processing capacity as shown in Table IV, and when

TABLE IV
Processing Capacity

Processing Run	Transactions Per Quarter (or Queries)	Statements per Transaction (or Query)	Total Statements Executed per Qtr (x 1000)
BOM File Maintenance	37500 + 50000 + 2500 = 90,000	1050 x 1/2 = 525	47,250
FIC to IIC Translation Table Maintenance	40,000 + 37,500 = 77,500	200 x 1/2 = 100	7,750
PCS Maintenance	50,000 + 1,000,000 = 1,050,000	750 x 1/2 = 375	393,750
Requirements Generation	30,000 + 75,000 = 105,000	350 x 1 = 300	31,500
RSS Transactions Generation	20,000 NSN's	100 x 1 = 100	2,000
Queries	8000 + 2000 + 2500 + 500 + 3000 = 16,000	300 x 1/4 = 75	1,200
Total	-----	-----	483,450

applying the 10 percent annual growth factor, the total quarterly execution time during the tenth year of operation amounts to:

$$483450 \times 10^3 \times 40 \times 10^{-6} \times \frac{1}{3600} \times (1.1)^9 \approx \underline{12.7 \text{ hours per quarter.}}$$

$(\frac{\text{statements}}{\text{qtr}})$ $(\frac{\text{sec}}{\text{stat.}})$ $(\frac{\text{hours}}{\text{sec}})$

During the first year of operations the system will require only 5.00 hours per quarter.

5. Conclusions

The resources that are required for running the MRP application are relatively small. The computations above have taken into account not only the MRP system but also the PCS. Even including future growth, the processing time does not justify devoting a computer to this application.

The conclusion is that the application should be run on an existing system and the system that appears to be appropriate is ASKARS. The reasons for selecting ASKARS' computer system are three-fold:

1. The MRP system plans materials which are carried and later handled by ASKARS.
2. ASKARS is a redundant system and therefore the additional load on the system would be insignificant.
3. The ASKARS system will hopefully have skilled ADP personnel (as opposed to the PDP 11/70 on which the temporary system runs) that could handle such a project.

H. COSTS AND BENEFITS

The purpose of the following analysis is to compare the costs involved in implementing the proposed system and to explore the benefits it will provide.

The costs involved in implementation of the MRP system are of two types: one-time development costs (software development) and recurring costs for software and hardware maintenance, supplies, personnel, and payments for computer time. Although ASKARS' processing and peripheral equipment have already been accounted for ("sunk cost") we will assume in this analysis that there is a capital cost associated with using the MRP application in ASKARS and that it can be computed according to the proportion of CPU time the MRP uses relative to the total CPU time available. We will also assume that the annual depreciation cost of this equipment is 10 percent of the purchase price. Consequently, the annual allowance for hardware is

$$HC = [PC/10] \times [T_1/T_2]$$

where: HC = annual allowance for MRP hardware costs

PC = purchase costs of the complete system

T_1 = CPU time for MRP. We will assume an average of 10 hours per quarter (see section G.4 of this chapter).

T_2 = total CPU time available per quarter. Since there are two processors,
 $T_2 = 2 \times 90 \times 8 = 1440$ hours.

Since the procurement of the ASKARS system is now in the bidding phase we will assume that the cost of the ADP equipment

is 50 percent of the total cost of the ASKARS system. The latter is estimated to be \$2,513,500 [26]; consequently, the cost of the ADP equipment in that system would be approximately \$1,257,000. Using these figures, the hardware costs would amount to less than \$1000 per year.

Allowing 10 percent of that amount for hardware maintenance, the MRP's share of hardware maintenance costs will be approximately \$100 per year.

Software maintenance will be assumed to require one programmer and 1/6 of one analyst (based on development personnel). In addition, the system will need two clerks for handling inputs and outputs. Using an average annual salary of \$30,000 a year, including fringe benefits, the personnel costs for software maintenance and operations would be:

$$(1 + 1/6 + 2) \times 30,000 = \$96,000 \text{ per year.}$$

When using the software development times from Appendix C and the above annual salary, the development and training expenses amount to

$$\left(\frac{75.5 + 14.2 + 0.2 + 1.0 + 8.0}{12} \right) \times 30,000 = \$247,250$$

To that we have to add processing time of approximately three months during the development period ($HC \times 4/2 \approx 330$) to get a total of \$247,580 for development costs, or approximately \$25,000 annually to be added to the recurring costs. When adding all these costs, we find that the annual costs of running the system are \$122,100.

The benefits from implementing the system are more difficult to measure, although relatively easy to identify. The system will provide the material planners a good data base on which they can base their decisions. It will also save them time by providing the necessary reports and inquiry capabilities (although this is not intended to totally replace their being in the shops!). The system will also provide a better requirements forecast and thereby improve availability of materials for repair and availability of ready-for-issue items that would not be delayed in the process of repair. Another area of savings is in workers' time. Because of improved availability of materials, work stoppages are expected to go down, thereby reducing the need for "backrobbing" (i.e., removal of parts from an aircraft/component for use on another aircraft/component with an earlier scheduled completion date [21:16]).

Another very important advantage of introducing MRP is the fact that the improved forecast should lower the amount of money tied up in inventories and should release that money for use elsewhere.

The factors that have been mentioned above gave a qualitative description of the benefits; quantifying some of them will clarify the description. During the period 1 April 1978 thru 31 March 1979 NARF Alameda's work centers charged 21,186 production delay hours to backrobbing. These hours represent a cost of more than \$860,000 [21:16] per year. Expenditures on material planners' salaries amount to approximately

122 x 30,000 = \$3,660,000 a year. Saving 1 percent of their time represents \$36,600 per year and the system will doubtless save more than that. When adding to that the money expended by the NARF on materials--being almost \$60 million in 1978 [22]--it becomes obviously clear that the annual benefits will exceed the \$122,100.

Another aspect that is worthy of consideration is that the MRP system may also be implemented at other industrial activities in the future so that the initial investment in this system can be expected to reduce the investment in those future systems.

I. IMPLEMENTATION PLAN

Implementation of the proposed system should consist of the following phases:-

1. Establishing a development team.
2. Software design, programming and documentation.
3. Conversion of the data base.
4. Testing.
5. Training and parallel operation.
6. Post implementation reviews and improvements.

The development team should consist of systems analysts, programmers and user representatives and should be responsible for preparing a detailed implementation plan, detailed system design and implementation of the system. This thesis would provide the team with design guidelines.

The various activities that take place in each phase are described in detail in Appendix C. Figure 32 gives anticipated project schedules for implementation of the system as well as the system development activities and human resources that are needed in each phase.

When going into actual implementation, it will be very important to keep in mind Woolsey's [24] "Ten ways to go down with MRP." Among others that he mentions, the following should be regarded carefully here:

1. "Only involve the highest level of management in defining the 'hands-on' side of the system."
2. "Don't run the system in parallel, just shut down the manual system and turn on MRP."
3. "Don't clean up your bills of materials, you know they are right."
4. "Don't require sales to take responsibility for screwing up the master production schedule."
5. "Install the system as a surprise to Production and Sales."

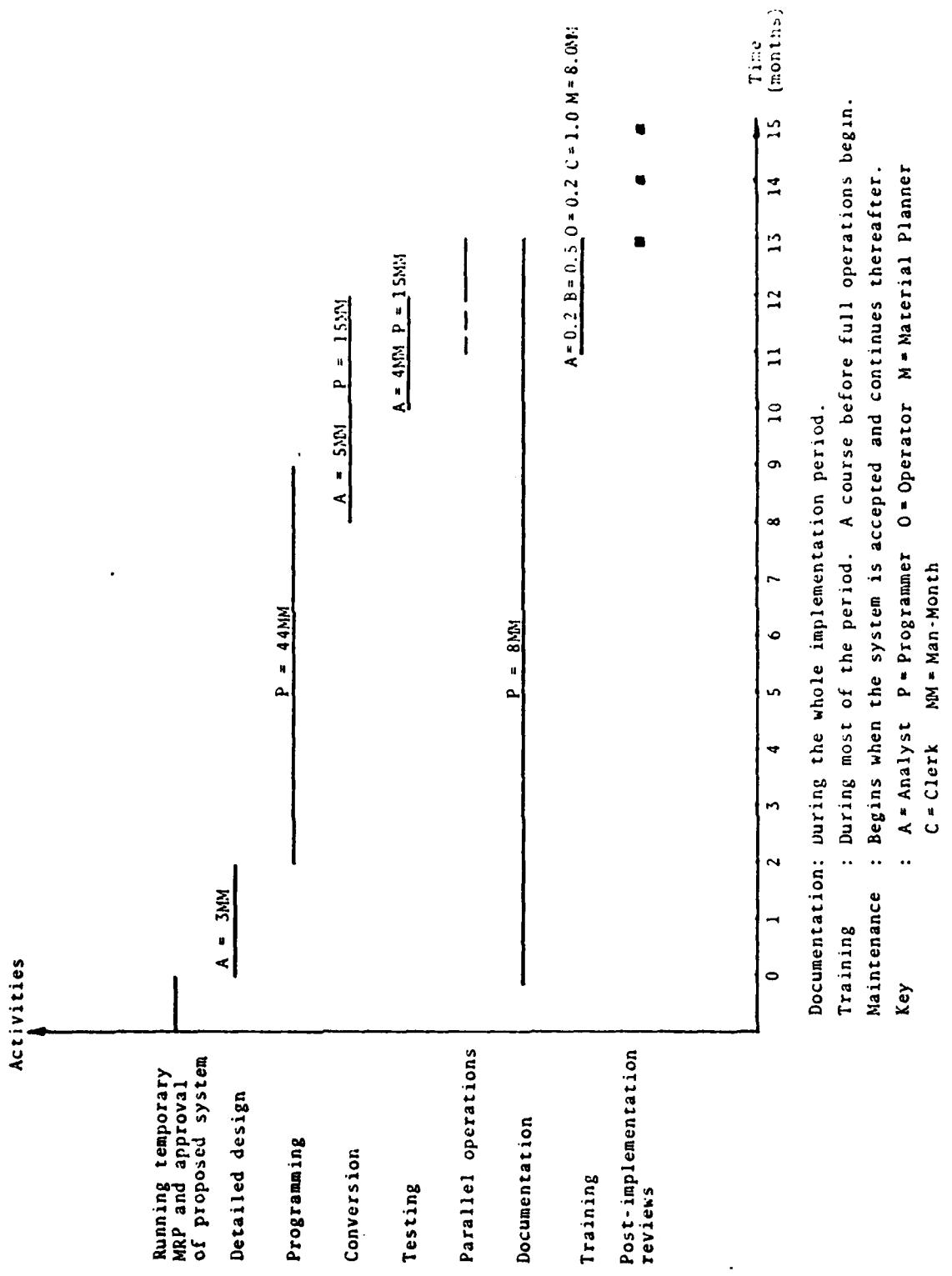


Figure 32: System Development and Implementation Activities

VI. CONCLUSIONS AND RECOMMENDATIONS

The MRP technique is designed to use the fact that the material requirements in a production or maintenance oriented environment are driven by the production schedule. However, the technique will only work if an accurate BOM and production schedule exist.

The system that is proposed in this thesis is designed to provide the means for developing and maintaining an accurate data base. Additionally, it provides a model that will use that data effectively to generate a realistic materials forecast.

The analysis of the temporary MRP system and its development as well as the design of the system proposed in this thesis have identified some problem areas that will have to be considered carefully in the course of implementing both of the systems. These problems are:

1. System Development

The process of developing any system requires analysis and design by a team that has the time and competence to do the job. The implementation of the proposed system requires assignment of a team that will be responsible for reviewing the temporary system, preparing the detailed design for its successor and implementation.

2. Planning Horizon

The proposed system was designed to meet the constraints imposed by the current budgetary process and the quarterly preparation of the production schedule. This implies that the system does not have the capability to forecast long run requirements, nor can it provide all requirements, a procurement lead-time ahead to assure that all materials are purchased so that all scheduled jobs can be accomplishable. This situation can obviously be improved significantly by developing long run production schedules and trying to stick to them as much as possible. This appears feasible for at least the engine and components programs that represent a major part of the workload schedule [21].

3. Frequency of Requirements Generation

Setting of the RSS stock levels is currently limited to once per quarter. This corresponds to the current frequency of determining the production schedule. It may be eventually useful, however, to regenerate the material requirements and reset levels on a monthly basis, thereby decreasing the influence of the random part of the forecast. However, the system should be used at least for one year with the present frequency to determine its performance before any changes are made.

4. Coordination with the UICP

The MRP forecast cannot be effective if the UICP system does not assure the existence of the required materials within the wholesale system. Since the problem is related to all NARF's and not just to Alameda it would be useful to

coordinate the operation of both systems so that the IICP could use the long-run forecasts from the MRP system as planned program requirements.

5. ASKARS and NISTARS

Although these two systems are being developed independently, there will undoubtedly be a need for communication between the systems. NISTARS will provide the storage space for the RSS and will also maintain a data-base which contains vital information for the NARF's day-to-day operations (for example, inventories on hand). Therefore, setting up an appropriate interface between the systems to allow direct access of one system to the other's data-base can simplify file maintenance in general and service to the users in particular.

6. FIC's and IIC's

The practice of preparing the production schedule by FIC introduces uncertainty into the process of planning material requirements and complicates the maintenance of the MRP system. Transition to planning by IIC will make the whole process much more accurate and efficient.

A rather different subject is the relationship between ASKARS and MRP. It so happened that the ASKARS system will become operational at the right time for implementation of the proposed MRP system. However, the interaction of two new systems may be very disastrous and therefore it is recommended that the actual implementation of the MRP system be delayed until most of ASKARS' "birth problems" have been resolved.

This delay time should be utilized to get better acquainted with the MRP system through the experience with the temporary system and to purify the data-base. This period should also be used for further analysis of the parameters needed for the proposed model.

Another area that is related to the MRP system and requires further analysis is the policy of overhauling complex end-items, especially aircraft. The current policy is that whenever an end-item is overhauled its repairable components are also overhauled and placed back on the same aircraft. This delays the completion of the job and calls for inductions of components separately from the regular induction of such components being repaired and placed in the supply system.

The MRP system would operate best if repaired components from stock were used in the aircraft overhaul and components from the aircraft that needed rework were returned to the supply system as non-ready-for-issue inventory. The advantage of this policy with respect to MRP is that it provides more accurate values for the replacement factors. As mentioned earlier, it is desired to make the decision about this subject before conversion to the proposed system to save later changes in the BOM data.

As to application of the project system to other activities, it appears that the model may be appropriate for other industrial activities to use. However, any action in that direction should probably not take place before the model proves its

effectiveness at NARF Alameda. Much will undoubtedly be learned which would serve to save time and effort for other applications.

APPENDIX A
LIST OF SELECTED UADPS-SP FILES [18]

1. Master Stock Item Record (MSIR). This is the master inventory status file.
2. Planned Requirement/Reservation File (PR/RFS).
3. Receipt/Due File (R/D).
4. Requisition Status File (RSF).
5. Demand History File (DHF). Together with the RSF, represents the demand history.
6. Address Master File (AMF).
7. Job Order File (JOF).
8. Master Employee Record (MER).
9. Receipt History File (RHF).
10. Transaction/Reconstruction File (TRANSRECON).
11. Demand Master File (DMF).

APPENDIX B
SUPPORTING DATA³

1. Supporting Data

The information to follow is required for estimating the size of files, processing times, and the required storage resources for the proposed system. The estimates are based on analyses of the present inventory system at NSCO and the temporary MRP application.

General Data

Approximate number of active FIC's = 10,000

Approximate number of active IIC's = 14,000

Maximum number of IIC's per FIC = 50

Average number of consumable NSN's per IIC = 50

Maximum number of consumable NSN's per IIC = 1,200

Average number of shops participating in IIC overhaul = 12

Maximum number of shops per IIC (all that exist) = 150

Number of active NSN's (used by the NARF) = 35,000

Number of active job orders = 28,000

Number of material planners = 120

2. Transactions Volumes and Processing Frequencies

Table B-1 describes the different software modules, and the type and volume of transactions processed by each module.

³Obtained from personal interviews with LCDR W.P. Benefiel, 500 Department, NARF Alameda, February 1980.

TABLE B-1
Transactions, Volumes and Processing Frequencies
for the Proposed MRP System

Software Module	Name of Transaction/Program	Number of Transactions/Runs
File maintenance	<u>BOM</u> Induction data Requisitions Estimation transactions BOM update run <u>FIC to IIC Translation Table</u> QFT transactions Induction data Table update	150,000 per year* 200,000 per year* 10,000 per quarter Once per quarter 40,000 per quarter 150,000 per year Once per quarter
PCS	Status transactions Expended hours transactions File maintenance run Production schedule listing Exception report Queries	50,000 per quarter 1,000,000 per qtr Weekly run Monthly Monthly 3,000 per quarter
Queries	Inquire BOM by IIC Inquire BOM by FIC Inquire MRP forecast Modify MRP forecast	8,000 per quarter 2,000 per quarter 2,500 per quarter 500 per quarter
Requirements generation	Expended materials transactions "Raw" material requirements RSS level setting transactions	30,000 per quarter 75,000 per quarter 20,000 per quarter

*The figures are inflated to represent overload during war time

APPENDIX C

SOFTWARE DEVELOPMENT

1. Software Development Activities

The development of the MRP software will involve the following activities:-

a. Design and Programming

Detailed specifications have to be written for each software module, file and processing run. These specifications will then be translated into computer programs which will be later tested to assure their compliance with the design.

b. Conversion

This phase involves preparations and actual conversion from the temporary MRP system to the proposed application. To do this, special programs will have to be written to convert the old data base to the new structure and to insert default values in those fields that did not exist before.

Because of the nature of the application it is possible and very desirable to operate both systems in parallel for one quarter. However, when the final system is accepted it would be appropriate to have a short (say, two days') break in running the application. This period would allow all the transactions in the old system to be processed and the "live" conversion to take place.

c. Testing

This phase includes testing of individual software modules, programs and processing runs. Different transaction paths and options of the system should be tested to make sure that it all works as expected.

The end of this phase involves a user's acceptance test during which the user tests the system, and then accepts responsibility for normal operations if the test is successfully passed.

d. Parallel Operations

While the old system is still running, the new one should run in parallel. This will allow the new system to be checked out before the old system is shut down. This phase also allows the users, and especially the material planners, to get acquainted with the new system, learn how to inquire and how to use the system's output.

e. Documentation

Documentation of the system should be done during the entire course of the project. At the early phases, the emphasis should be on documenting decisions and reasons for selecting specific options or procedures. In the later stages the emphasis should be on documentation of the software, data-base, input, output, and use of the system.

The documentation should cover all modules, the interfaces between the modules and interrelation between the modules. Operational manuals should be provided describing

regular operations and actions to be taken when irregular events ("bugs") occur.

f. Training

Involvement of the users in the early design stages will pay off when time for training comes. However, training should be provided to all users and people that are involved in running the system (operators, I/O clerks) to assure that they know how to handle the inputs and how to use the outputs and the services the system provides.

g. Post Implementation Reviews

After the system goes into normal operation, it would be very desirable to have at least one or two post implementation reviews. These are meetings of the development team and the users in which problems are brought up and discussed. If there are problems, the group should identify its source and find a solution that will satisfy the users. However, it is advantageous to collect requests for small changes rather than implementing each one as it comes up. In addition, these changes should be examined to see if they are really needed.

2. Development Times

The cost of the software development will be based on the size and complexity of the different modules [25]. The following productivity standards will be assumed in this process:-

1. Programming -- Fifty source, high-level-language statements per programmer per week (for simple level 1 complexity programs). A statement in a simple program will be the "standard unit."

2. Testing -- 150 statements of complexity 1 per programmer per week.
3. Documentation -- 15 percent of total programming and testing time.
4. File Conversion -- approximately the same as file maintenance.
5. Training and Parallel Operation -- two training days for each user/operator.

Table C-1 shows the derivation of the total size of the software (in "standard" statements) and allows derivation of the software development times as follows:-

1. Programming time = $8650/50 = 173$ man-weeks ≈ 44 man-months.
2. Testing time = $8650/150 \approx 58$ man-weeks ≈ 14 man-months (8 programmer man-months and 4 analyst man-months).
3. Documentation time - $(44 + 11) \times .15 \approx 8$ man-months.
4. File conversion time = $(2250 + 300 + 1500)/50 \approx 81$ man-weeks ≈ 20 man-months (15 programmer man-months and 5 analyst man-months).
5. Training and parallel operations time involves:
 - a. 0.5 programmer man-months.
 - b. 0.2 analyst man-months.
 - c. 0.2 operators man-months.
 - d. 1.0 clerk man-months.

In addition to that, analyst time is required for preparing the detailed specifications for the MRP application. Based on the time that this study took, it is estimated that 3 more man-months of analyst time are required.

Adding together all elements gives the following times:-

1. 75.5 programmer man-months.
2. 14.2 analyst man-months.

TABLE C-1
Software Size

Module	Program	Source Statements	Complexity	Standard Units
File Maintenance	BOM-- Input edit	250	1	250
	Extract	50	1	50
	Update	750	3	2250
	FIC to IIC translation table			
	Extract	50	1	50
	Update	150	2	300
	PCS-- Input edit	250	1	250
	Update	500	3	1500
Queries	Query "Driver"	100	2	200
	Query BOM	100	2	200
	Query MRP forecast	300	2	600
	Modify MRP forecast	500	3	1500
Requirements Generation	Extract inputs	50	1	50
	Generate forecast	250	2	500
	Reformat output	50	1	50
	Generate transactions	100	1	100
Subroutines functions and report generators	MRP subroutine	150	2	300
	Read/write functions	200	2	400
	IIC from job order	100	1	100
Total		3900		8650

3. 0.2 operator man-months.
4. 1.0 clerk man-months.
5. 8.0 material planners man-months (based on 120 planners).

These figures imply that the implementation of the system in a period of one year requires the employment of six programmers and one systems analyst. However, because the load is not equally distributed during the year it may well happen that at some times additional programmers (or overtime) and/or systems analysts will be needed.

APPENDIX D
UPDATING REPLACEMENT FACTORS

The replacement factor represents the proportion of a consumable item that is expected to be replaced when the end-item that includes that consumable is being replaced. The replacement factor is expected to change during the useful life of an end-item because of:

1. Aging of the item;
2. Changes in maintenance policies;
3. Estimated replacement factors found to be in error.

Consequently, there are two ways to update the replacement factor.

1. By Transaction

The transactions that are submitted by the material planners (see BOM file maintenance) will set the "estimated replacement factor" field in the BOM file to the value reported in the transaction and will update the "estimator code" and "date of last estimate" as well.

2. By Actual Replacement Information

During the BOM file maintenance run, actual replacement factors are computed. The actual replacement factor is the ratio between the total quantity of the item replaced in overhaul of a certain IIC and the total installed quantity of that consumable in the whole quantity that was inducted.

This new replacement factor will be used to update the "actual replacement factor."

Various methods exist for updating information such as the replacement factors. The most simple would be to compute a weighted average of the new and the old replacement factors where the weights are proportional to induction quantities. A variation on that would be a simple moving average [29]. This method is utilized in the temporary MRP system. The Exponential Smoothing method is still another method often used in such cases. Its big advantage is that it needs no other data but the old and new factors and the smoothing constant.

Forecasting usually involves a start-up problem. The information that is initially available is an estimate and the problem is how to phase it out and replace it by actual data as it becomes available. The intent of the proposed procedure for updating the replacement factors is to utilize information of both actual and estimated factors and to gradually phase in actual data so that as soon as sufficient actual experience is available the estimate will be ignored. To do that, two separate fields are maintained in each "consumable" trailer in the BOM file, one for the estimated replacement factor and the other for the actual factor. An additional field is used as a counter of the total induction quantity on which the actual replacement factor is based. The contents of the estimate field are derived from

transactions, each new estimate for an IIC/consumable overriding the previous one. The actual replacement factor is set to zero when the trailer is created and also whenever a new estimate is processed. At the first time an actual factor is computed, it will override the zero. In subsequent updates, a new actual replacement factor will be computed using exponential smoothing as follows:

$$F_{N+1} = 0.9 F_N + 0.1 F_A$$

where,

F_{N+1} is the new "actual" replacement factor,

F_N is the old "actual" replacement factor, and

F_A is the actual replacement factor computed from last quarter's data.

The determination of the replacement factor to be used by a program will be done by a subroutine. This subroutine will return to the calling program the replacement factor which results from the information in the fields containing the estimated factor, the actual factor, the date of estimation and the total induction quantity. The algorithm for determining the replacement factor is as follows:

1. If no actual factor exists, return the estimate.
2. If an actual factor exists and the date of the estimate is more than a year old, return the actual factor.
3. If the above conditions are not satisfied, compute the factor to be returned by exponentially smoothing the estimated and the actual replacement factors. The coefficient, α , to be used will be determined according to the total induction quantity. For example:

- a. If the induction quantity is less than 10, $\alpha = 0.1$;
- b. If the induction quantity is in the interval [10, 100], $\alpha = 0.5$;
- c. If the induction quantity is greater than 100, $\alpha = 1.0$.

The various parameters mentioned above, namely, the period before the estimate is totally phased out, and the intervals of total induction quantity for the variance α values, may have to be "tuned-up" after some experience is gained.

APPENDIX E
FURTHER DISCUSSION OF THE PRM-MRP MODEL

The Impact of a Budget Constraint

Suppose that a budget constraint exists and assume that the 100% replaced items are all purchased. In addition, assume that after the 100% replaced items have been purchased, a limited remaining amount of money from the NSF is expected to be available to buy the items replaced less than 100% of the time. If we denote this remainder as B , then our constraint on funds results in

$$\sum_{i=1}^m C_i y_i \leq B$$

where $C_i y_i$ is the total cost of buying y_i units of repair part No. i .

If we solve for the individual values using equation (5) it is possible that these values will result in

$$\sum_{i=1}^m C_i y_i > B .$$

However, this may not always be true and therefore it is appropriate to determine these "unconstrained" values of the different y 's and test them against the constraint. If, indeed, the budget constraint is satisfied then we have the correct optimal y values.

If the budget constraint is not satisfied, the technique of Lagrange can be used to get a modified form of equation (5); namely,

$$\bar{F}(y) = \frac{C_p + C_h + [k + \theta]C}{\pi_1 + kC} \quad (9)$$

The approach is then to introduce trial values of θ , determine the resulting set of y values using equation (9), compute the associated sum

$$\sum_{i=1}^m C_i y_i ,$$

and compare it with B . If the sum is less than B the value of θ should be reduced; if the sum is still greater than B the value of θ should be increased. The search terminates when a value of θ results in the sum being equal to B . The associated y_i values are the budget constrained optimal quantities of the m repair parts to place in the RSS.

Is a Budget Constraint Appropriate?

The model developed above assumes a static situation in which the production schedule and the budget constraint are given. However, imposing both constraints in advance may have an adverse effect on the ability of the NARF to meet that schedule. It may well happen for a given component undergoing repair, that the items with 100% replacement will be available in stock whereas other items (for which $P < 1$) would not be there. Consequently, what may happen is that

instead of having complete kits of parts required to complete a job there will be only "partial" kits, i.e., all the parts replaced 100% of the time and some of those where $p < 1.0$. In such a case there is no way in which a job could be completed. Moreover, those parts that are in stock may remain useless because of the shortage in other parts.

The conclusion is that the proper way to go is to schedule jobs into the NARF so that the budget will be sufficient to provide all materials predicted by the model thereby, in fact, assuring that the constraint is not active. However, it might be logical to prepare a reserve of job orders for the case that actual consumption was lower than the forecast. The proper way to provide protection against such an event is to induct additional quantities of the items that have been inducted previously.

Reducing the Number of Scheduled Jobs because of a Budget Constraint

To avoid the problems described above, it would be natural to schedule jobs so that their material requirement would not exceed the budget vice changing the quantities of the materials placed in stock. To meet that goal, the original list of job orders should be split into groups of jobs, each group containing jobs of some priority. Then, the algorithm should be applied to each set of jobs to determine the budget it requires. When this step is completed, one can determine which jobs can be scheduled so that their material requirements would not exceed the budget, or on

the other hand, determine what increase in budget will allow the scheduling of some additional jobs.

The Back-up Stock (w) from the Wholesale Supply System

w is a variable quantity. Although the quantity of back-up stock is known at the start of the quarter or when planning occurs, the amount available at the time it is needed depends among others, on the demand the item experienced from other activities during the time from the start of the quarter until the time when the shortage occurred. It may be appropriate to use as w the amount of the item prepositioned as war reserves. However, this assumption requires having a permission to actually use that stock in the event that a shortage occurs in the RSS stock and the quantity in the regular wholesale supply is insufficient.

Perhaps a sensitivity analysis will provide guidance as to the appropriate assumptions to make about the value of w.

Which Constants to Use

The model requires the following constants:

C_p - Processing costs

C_h - Holding costs

π_1 - Shortage cost for item obtained from local wholesale supply

π_2 - Shortage costs for items obtained somewhere else

k - Surplus cost factor

It is logical to assume that these constants have specific values for each item used in repair of a component. It is

relatively simple to determine the values of C_p and C_h and it may as well be logical to apply these constants to groups of items of similar nature. This is not the case, however, with π_1 , π_2 , and k . The shortage cost depends not only on the item that is not available but also on the specific circumstances of a given job that requires the part and on the circumstances of other jobs. That is also true for k . Consequently, π_1 , π_2 , and k may vary from job to job, from part to part, and even from time to time for the same job/part. It may be useful to note that k can be viewed as the "knob" that adjusts the surplus cost [see equation (9)] in much the same way as is done in the UICP model where the "knob" is the shortage cost. Also, when a budget constraint is imposed, it may be viewed as increasing the value of the surplus cost resulting from k , causing a solution for y more in favor of a shortage.

Pragmatic Aspect

Maintaining the different constants for each item and, in particular, having it done by the NARF, would be prohibitively complicated. The system may become significantly more simple if the constants could be determined for groups of items rather than for each item. It seems logical to begin by establishing values spanning groups of items (and keeping those constants in a table that will be shared by different application programs).

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